Biological Agent Sensor Testbed*

MIT Lincoln Laboratory

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Biological Agent Sensor Testbed (BAST) Development Status

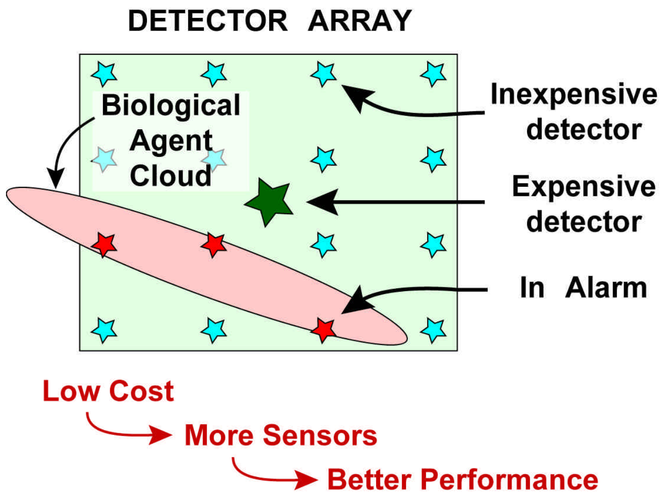
Biological Agent Sensor Testbed

- Motivation and Goals
- Sensor Concept
- Breadboard Apparatus and Data
- Engineering Development Unit Design
  - Optical
  - Electrical
  - Mechanical
  - Algorithm
- Summary

Motivation and Goals

- **The cost of current biological agent detection systems strongly limits the number of locations that can be protected.**

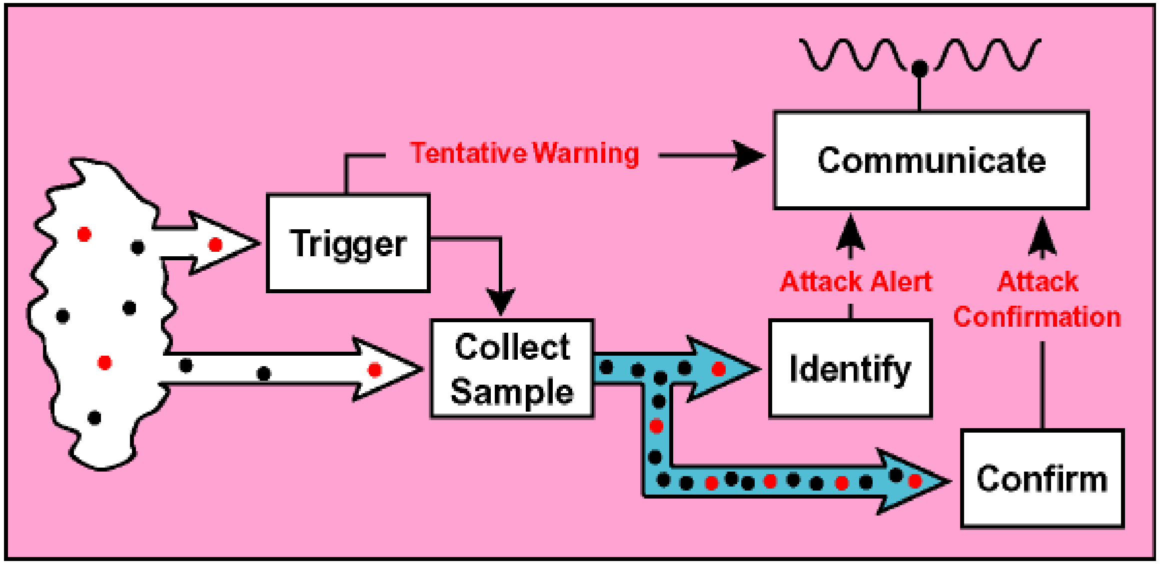
- **Needed: biological agent detection system that can be made in large quantities for the protection of many locations**
  - **Low cost**
  - **Good performance**
    - **sensitivity, false positive rate, probability of detection, response time**
  - **Willing to trade performance for cost, size, weight, and power**



- **BAST Goals**
  - **Low manufacturing cost (<$1000)**
  - **Low false positive rate (<1/Week)**
  - **Sensitivity < 500 ppl (98% detection confidence)**
  - **Response time < 60 sec**
  - **Small size (0.5 cu. ft.), low weight (<20 lbs)**

Biological Agent Detection

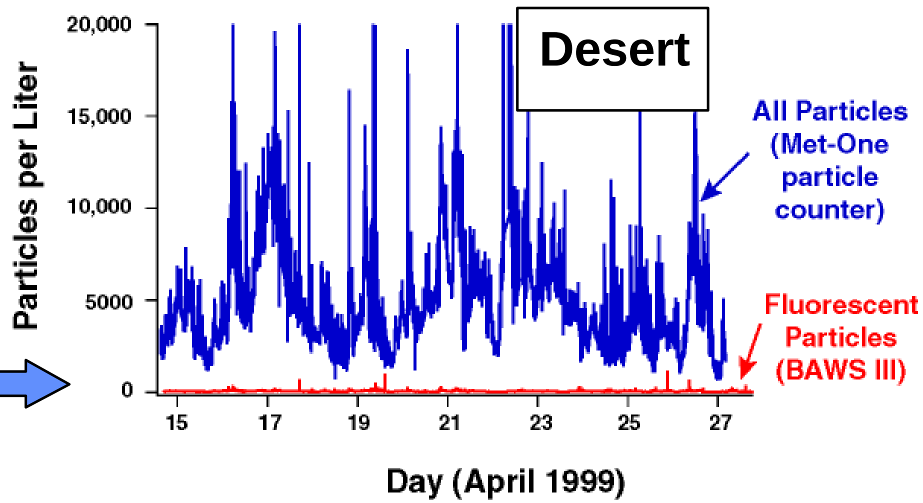
Typical Bio-sensor Architecture



Fluorescence Trigger

- Sensitive
- High probability of detection
- Fast
- Relatively low false positive rate

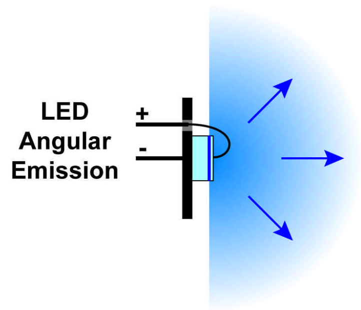
Fluorescent vs. Total Particles

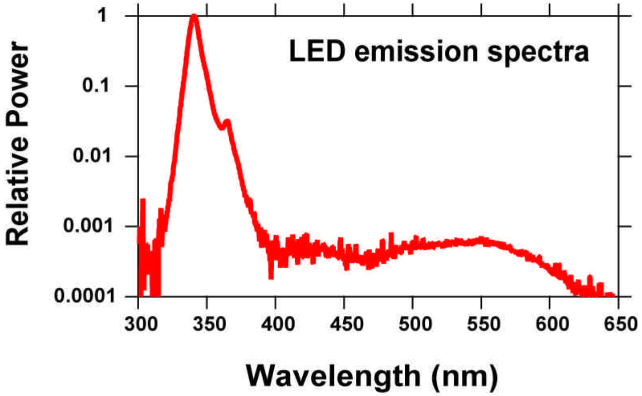


UV-LED-Based Biological Agent Detection

- **Advantages**
  - **Cost**
    - Enable low cost and small size sensors
  - **Performance**
    - Affordable large array networks for improved sensitivity
    - Multiple operating wavelengths for improved discrimination

- **Issues**
  - **Short wavelengths**
  - **LED lifetime**
  - **Low brightness**
  - **Relatively broad spectral emission**

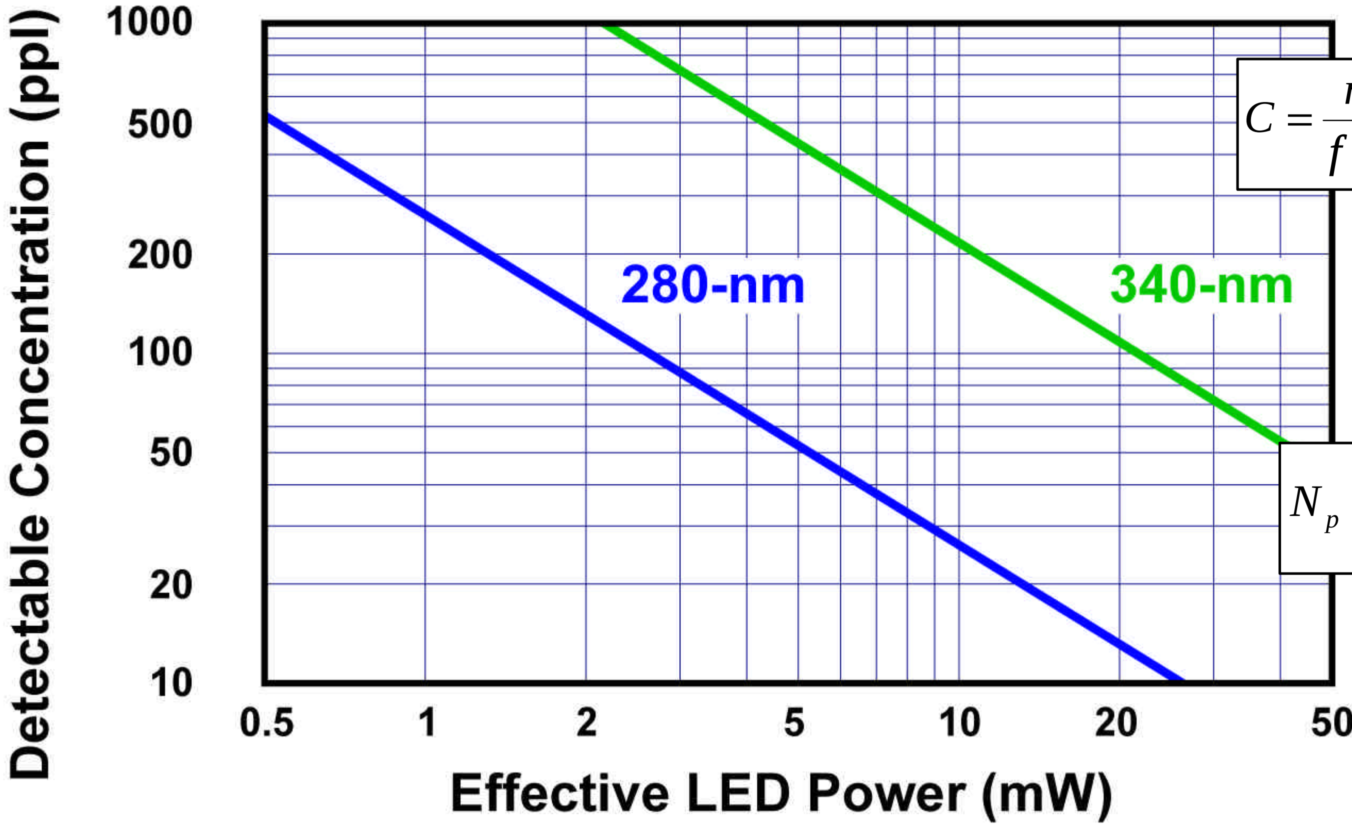




Sensor Concept

- Particle illumination with 280-nm and 340-nm LED radiation and with 820-nm laser diode radiation
- Detection of 280-nm and 340-nm LED induced side fluorescence
  - 300 – 400 nm (280-nm excitation) 1
  - 400 – 500 nm (280-nm excitation) 2
  - 400 – 500 nm (340-nm excitation) 3
- Detection of side elastic scattering (280 nm) 4
- Detection of forward elastic scattering at 820-nm 5
  - Measure particle size
- 5 independent measurement channels

Fluorescence Detection Analysis



$$C = \frac{n}{f\,T}$$

$$f = \frac{AL}{t}$$

$$N_p = h_c h_d \frac{P t\ l}{A h c} s$$

Number of detected particles (N_b)	100 particles
Particle fluorescence cross-section (s)	(50, 5) x 10^{-12} cm^2 @ (280, 340) nm
Number of detected photo-electrons (N_{pe})	100 photoelectrons
Photon collection, detection efficiency (h_d)	30% , 15%
Threat detection time (T)	60 s

LED Sources

280-nm LED

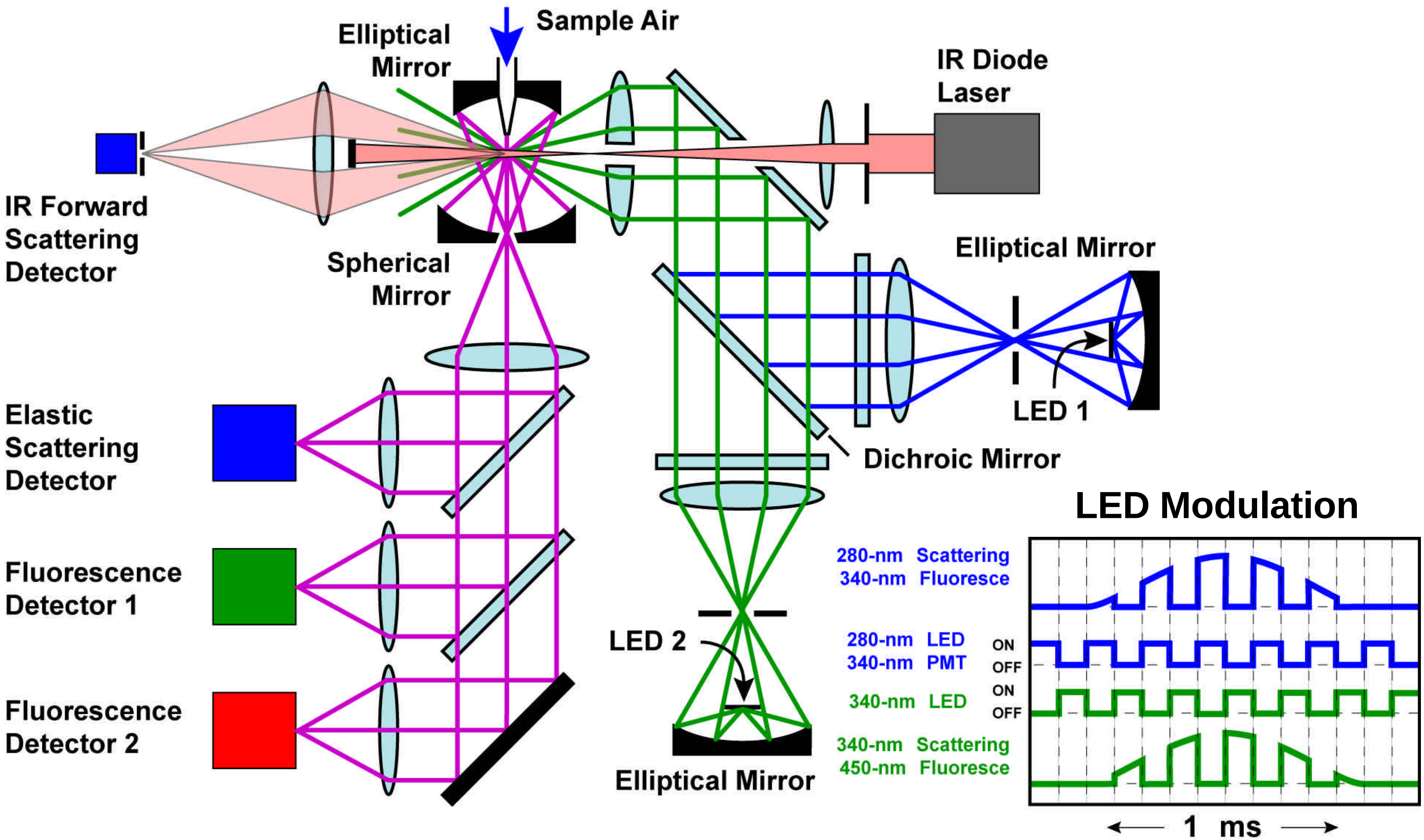
- **LED element**
  - 0.1-mm x 0.1-mm
  - CW 0.15-mW @ 20 mA
  - Pulsed 0.45-mW @ 70 mA
- **Small LED array**
  - 2x2 in 0.3-mm x 0.3 mm
  - CW 0.6-mW @ 100 mA
  - Pulsed 1.8-mW @ 150 mA
- **Large LED array**
  - 5x5 in 1-mm x 1 mm
  - CW 3.75-mW @ 100 mA
  - Pulsed 11.25-mW @ 150 mA

340-nm LED

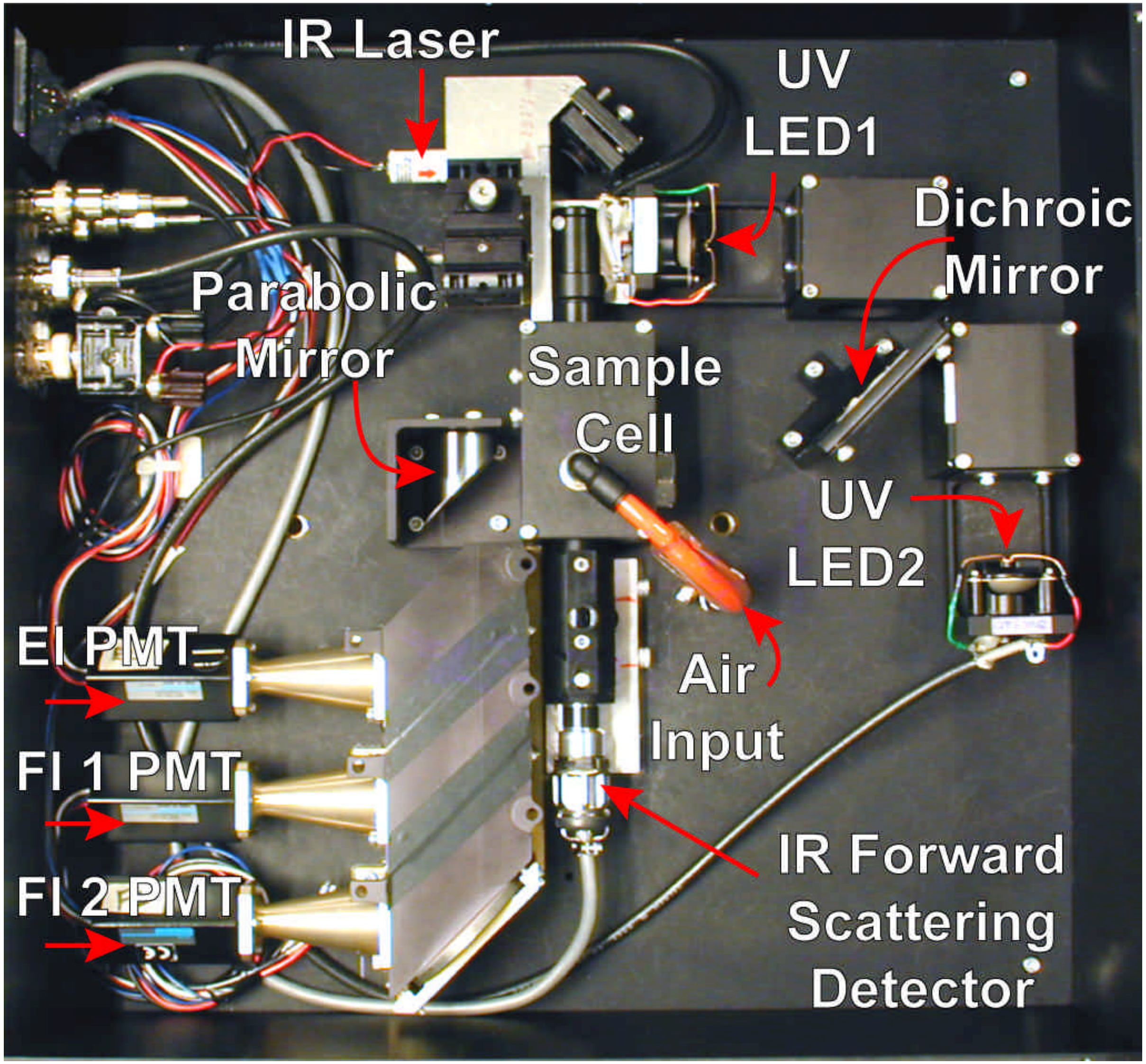
- **Small LEDs**
  - 0.3-mm x 0.3-mm
  - CW 0.8-mW @ 20 mA
  - Pulsed 8-mW @ 200 mA
- **Large LEDs**
  - 0.9-mm x 0.9 mm
  - CW 2.75-mW @ 100 mA
  - Pulsed 23-mW @ 1000 mA

All LEDs mounted on TO-46 headers.
Pulsed operation is for 1-ms pulse duration at 100-Hz repetition rate.

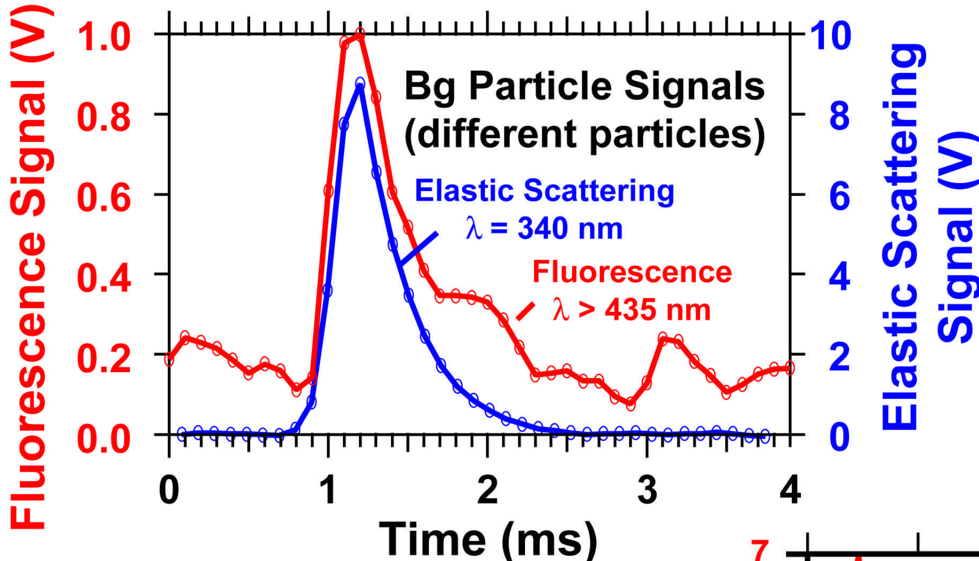
Optics Concept



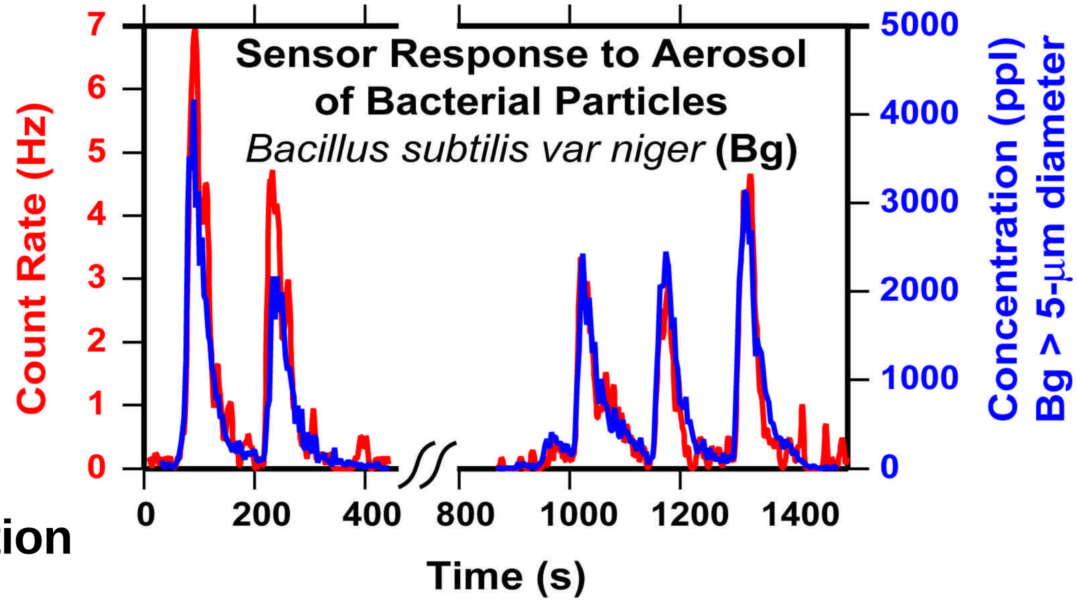
Proof-of-Concept Apparatus



Proof-of-Concept Fluorescence Data



Detection of aerosolized single particle biological agent simulants (Bg) using 340-nm Cree LED

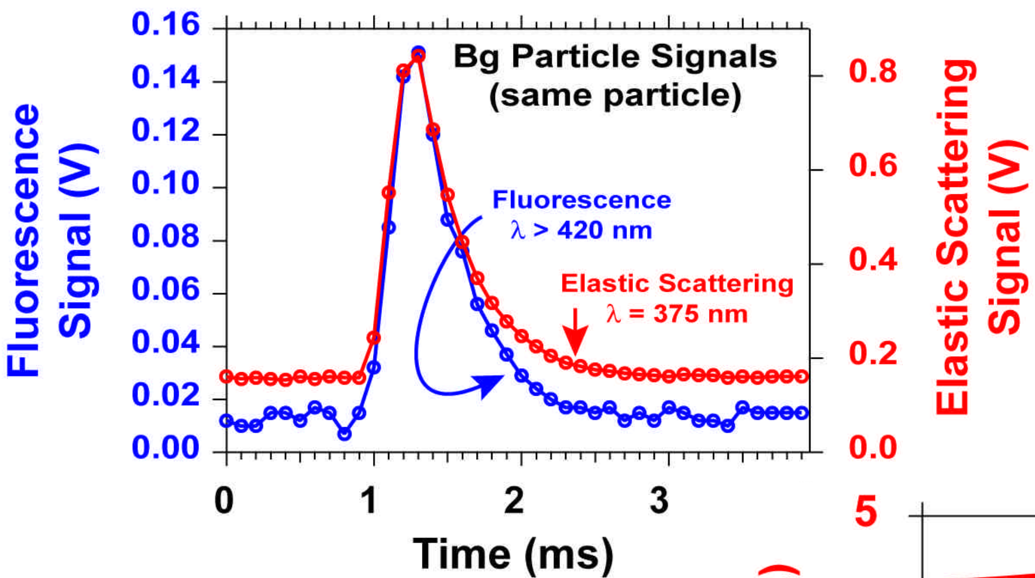


Responsivity

1 Hz count rate

700 ppl concentration

Proof-of-Concept Fluorescence Data

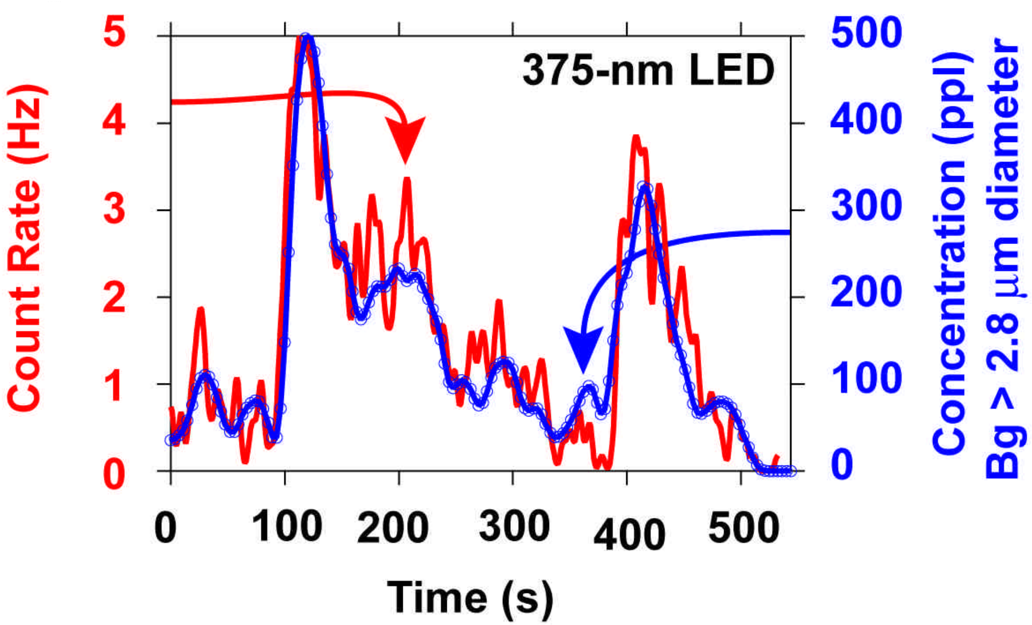


Detection of aerosolized single particle biological agent simulants (Bg) using 375-nm LED

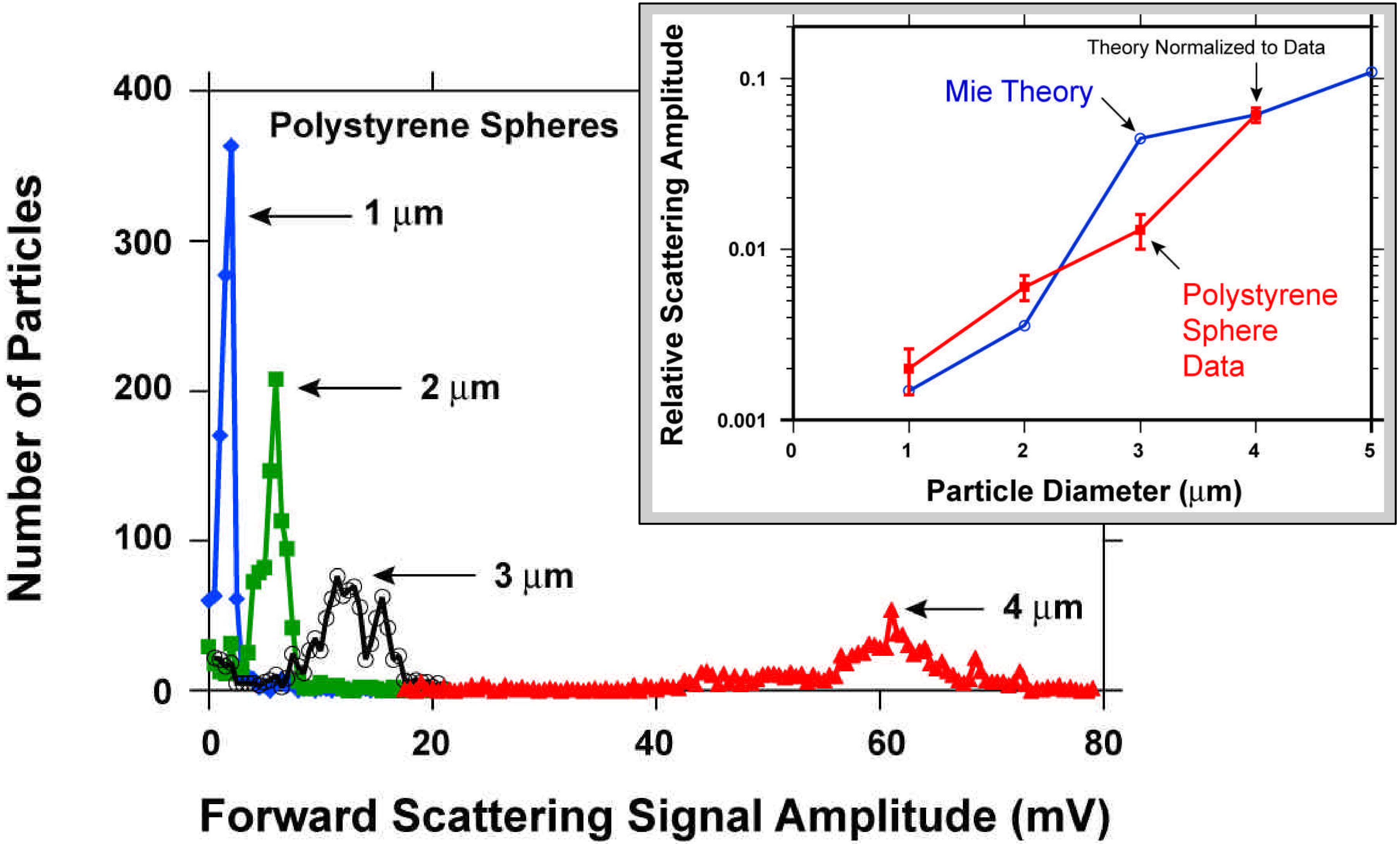
Responsivity

1 Hz count rate

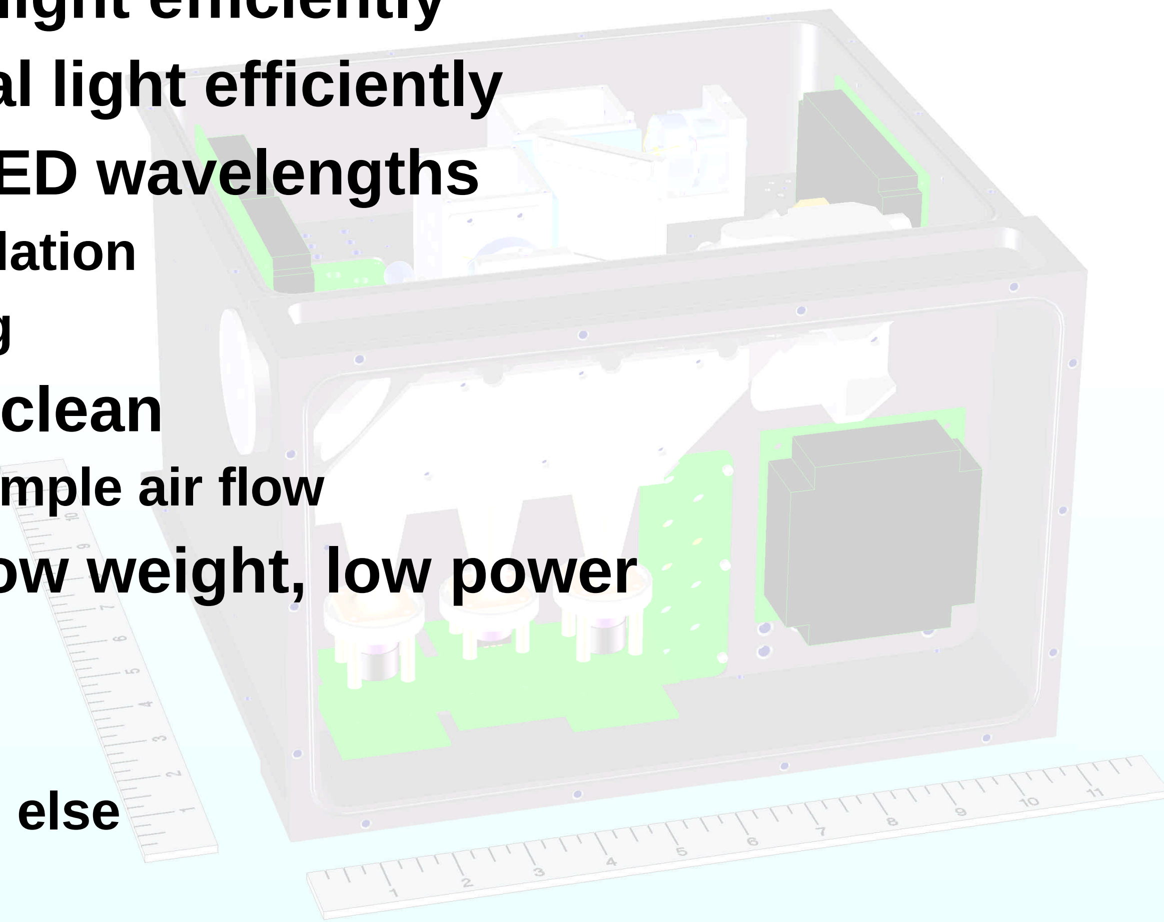
100 ppl concentration



Proof-of-Concept Particle-Sizing Data



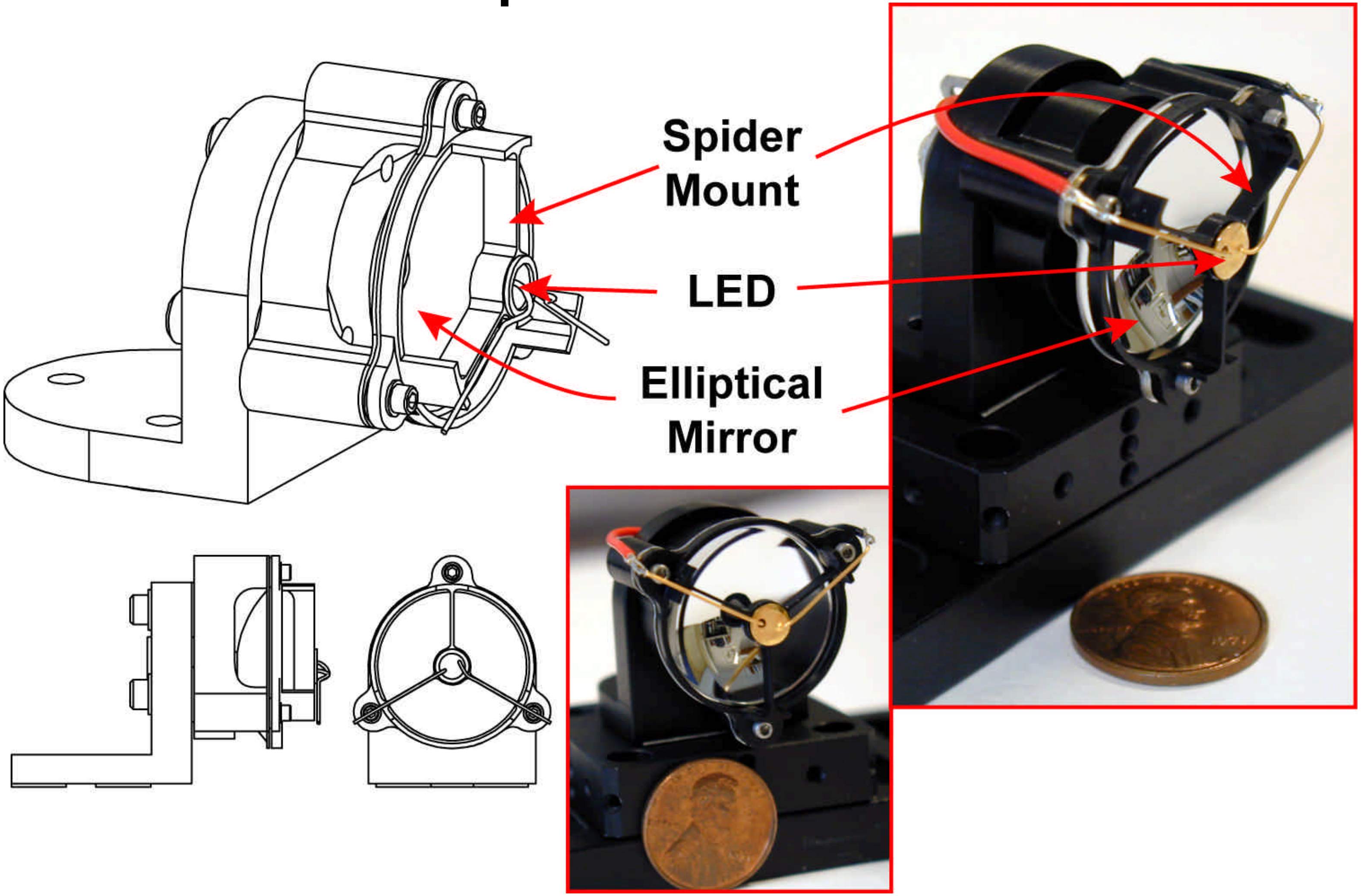
Engineering Development Unit: Challenges



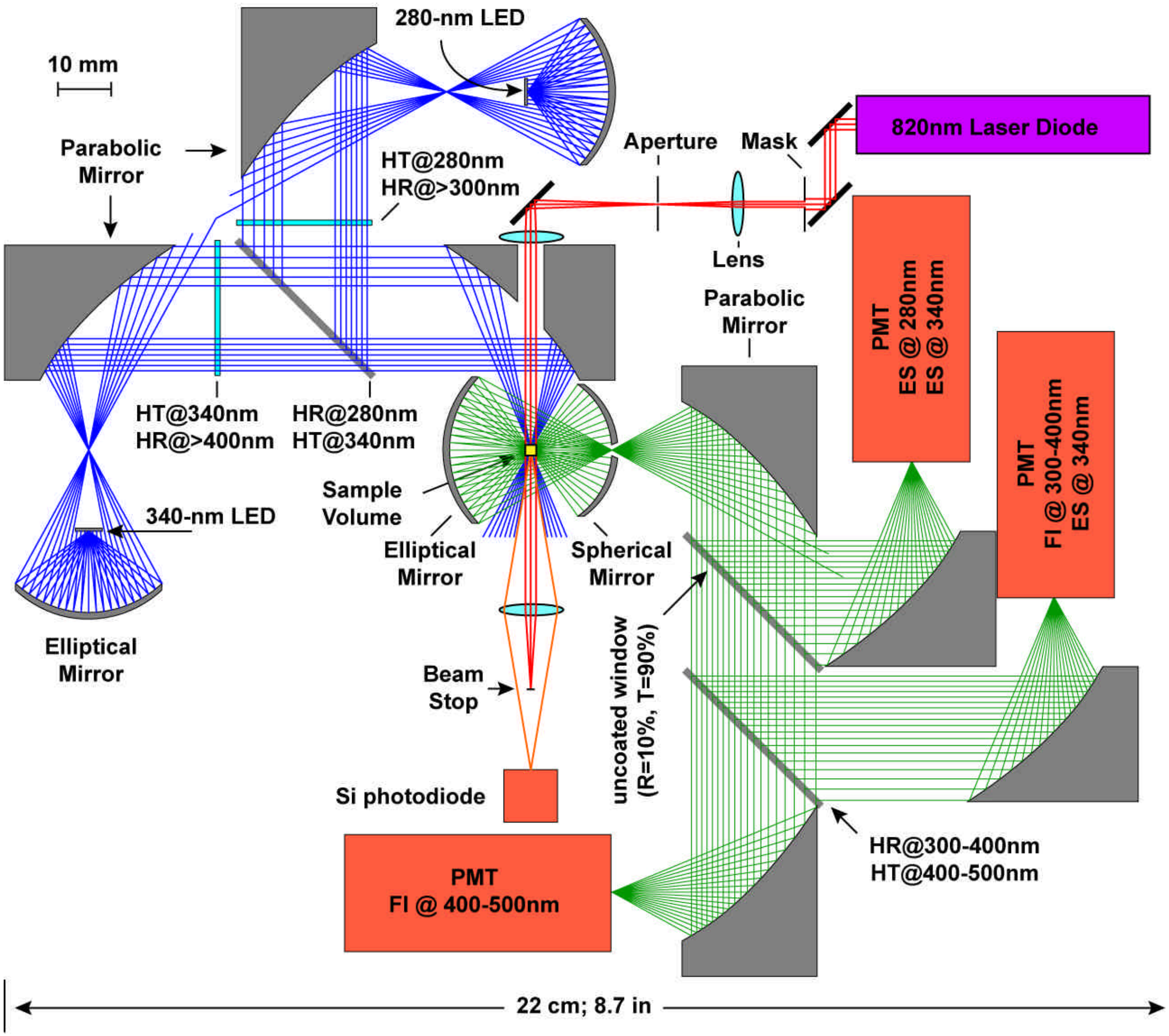
- **Collect LED light efficiently**
- **Collect signal light efficiently**
- **Utilize two LED wavelengths**
  - LED modulation
  - PMT gating
- **Keep optics clean**
  - Confine sample air flow
- **Small size, low weight, low power**
- **Low Cost**
  - LEDs
  - Everything else

Engineering Development Unit Design: Optics

LED Mount and Elliptical Mirror



Engineering Development Unit Design: Optics



Engineering Development Unit Design: Electronics

Electronics Functional Concept

Optical Signals → **Signal Capture And Pre-Processing** → Detection Algorithms and User Interface

Raw Measurements

- Elastic scattering
  - 288 nm
  - 820 nm
- Fluorescence
  - 300-400-nm
  - 400-500 nm
- Source Powers

→

Particle Qualities

- Normalized signals
  - Elastic
  - fluorescence
- Particle Size

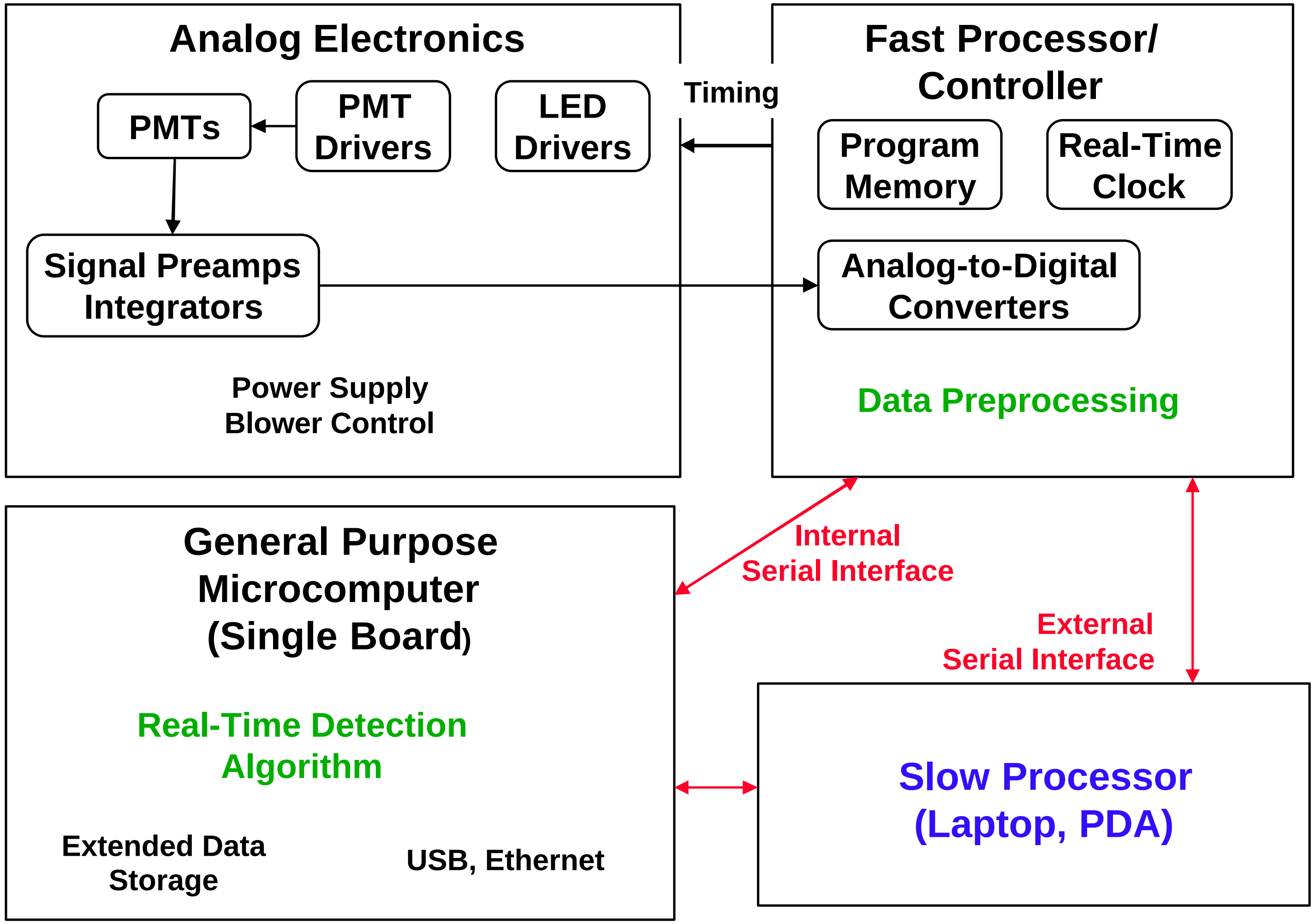
→

Event Detection

- Strength
- Type
- Trigger decision

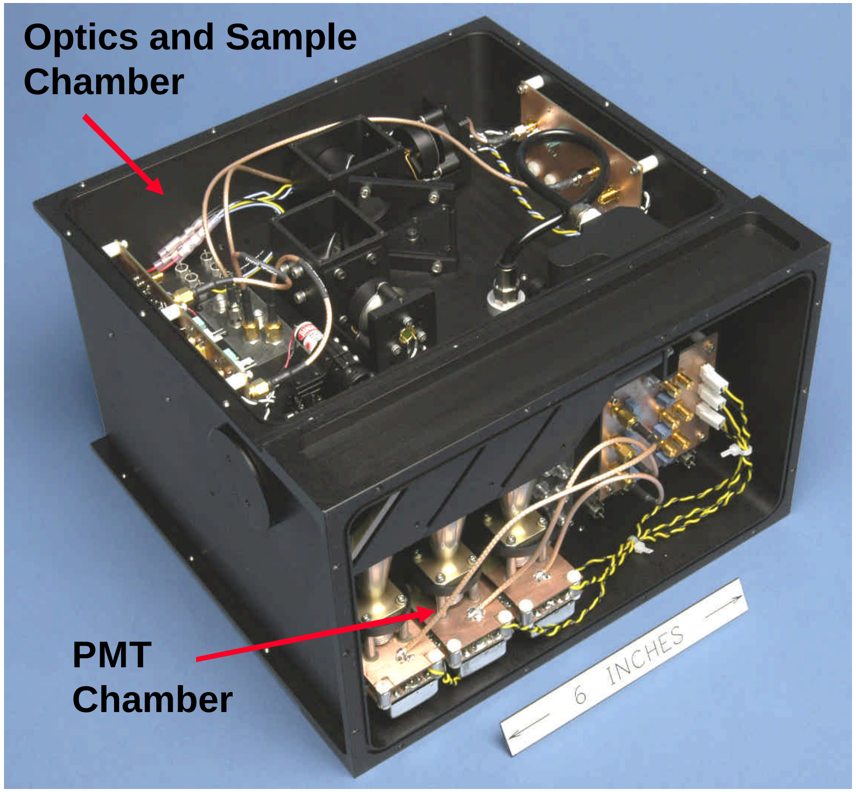
Engineering Development Unit Design: Electronics

Electronics Block Diagram

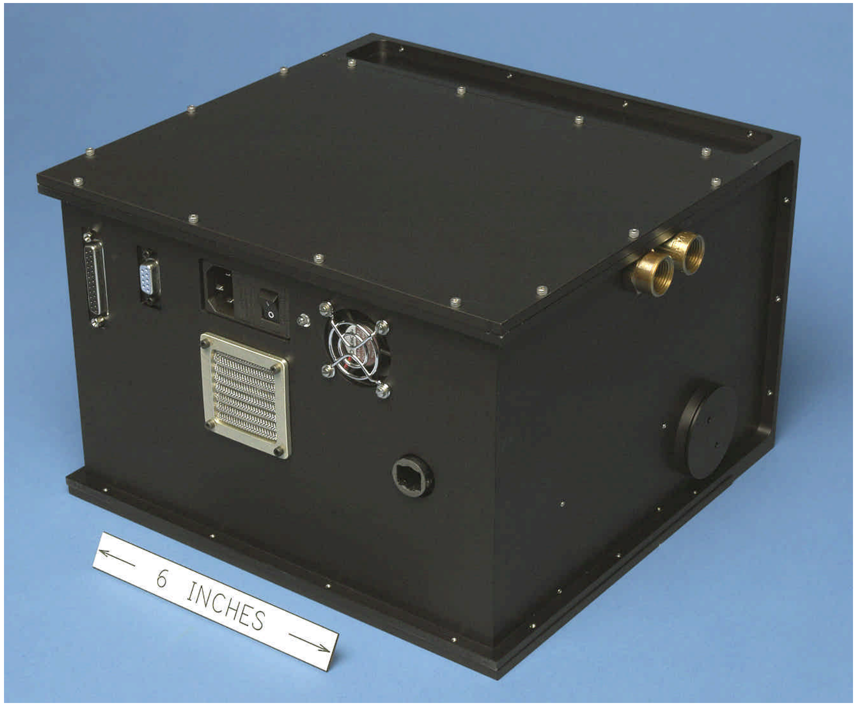


Engineering Development Unit Design: Mechanical

Covers Off



Covers On

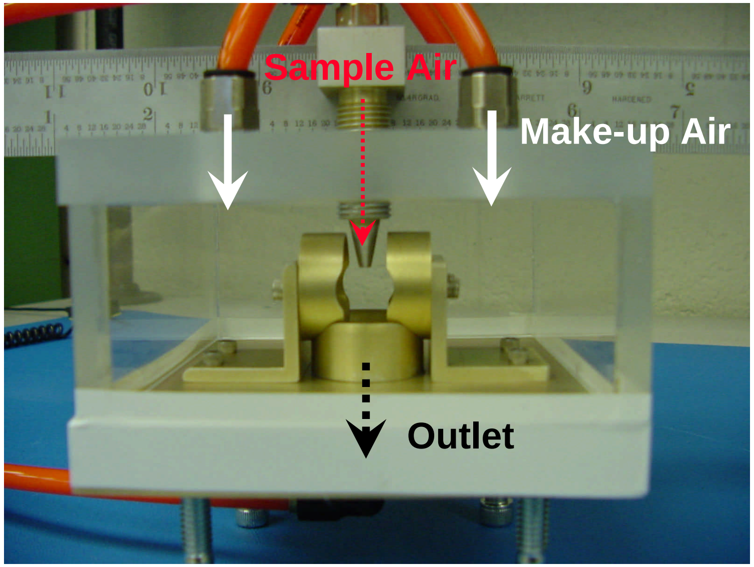


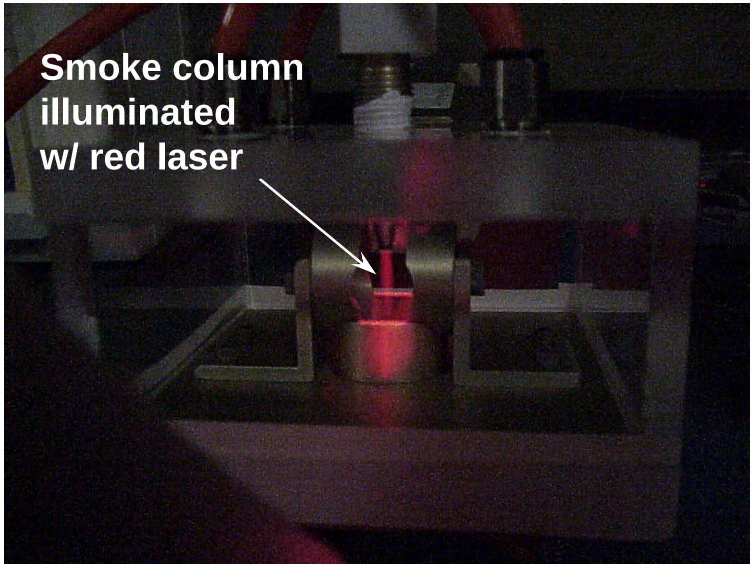
Compact design
Three compartments
Easy access to all compartments

Weight approx. 17.5 lbs
11.1” x 10.9” x 7.3”
Can be used in any orientation

Engineering Development Unit Design: Sample Air Handling

- Sample air contained in a free jet
- Additional make-up air confines sample air and prevents optics contamination
  - HEPA filtered make-up air
- Laminar flow
  - Straight particle trajectories
  - Well defined air speed
- Test apparatus constructed
  - Confirmed that make-up air isolates sample air





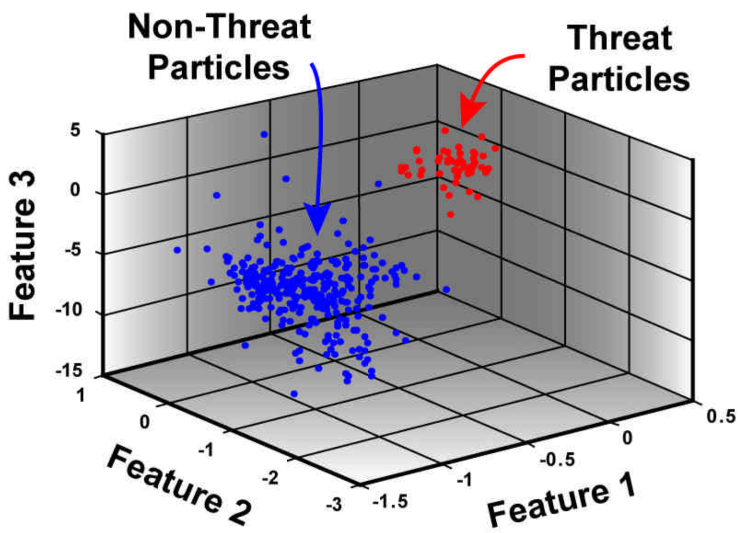
Engineering Development Unit Design: Algorithm

1. Training

- Learn background spectral signature in multidimensional space
  - Particle size
  - Fluorescence
  - Elastic scattering
  - Combinations of features

2. Change Detection

- Compare present aerosol spectral signature with background signature
  - Significant difference indicates new type of aerosol



3. Discrimination

- Determine if event occurred in threat region
  - Generate trigger event
  - Track multiple concurrent events
  - Report event strengths

Summary

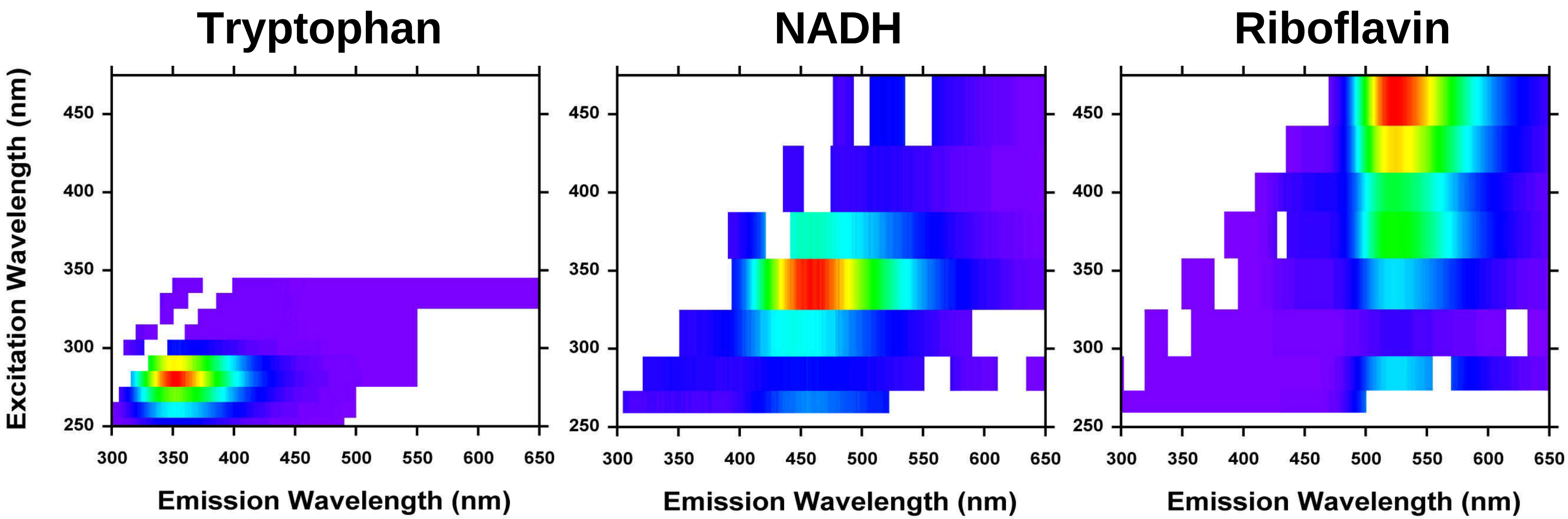
- **Analysis of LED based biodetection**
- **Design and construction of three test-bed generations**
- **First demonstration of LED based detection of biological agent simulants (*Bacillus subtilis var niger (Bg), ovalbumin*)**
- **Measurement of elastic and fluorescence aerosol signals using 280-nm and 340-nm LEDs**
  - **Bg, Ovalbumin, Dirt**
  - **> 3-μm Bg particle size**
  - **> 1 Hz per 100 - 700 ppl Bg responsivity**
- **Design and construction of engineering development unit**

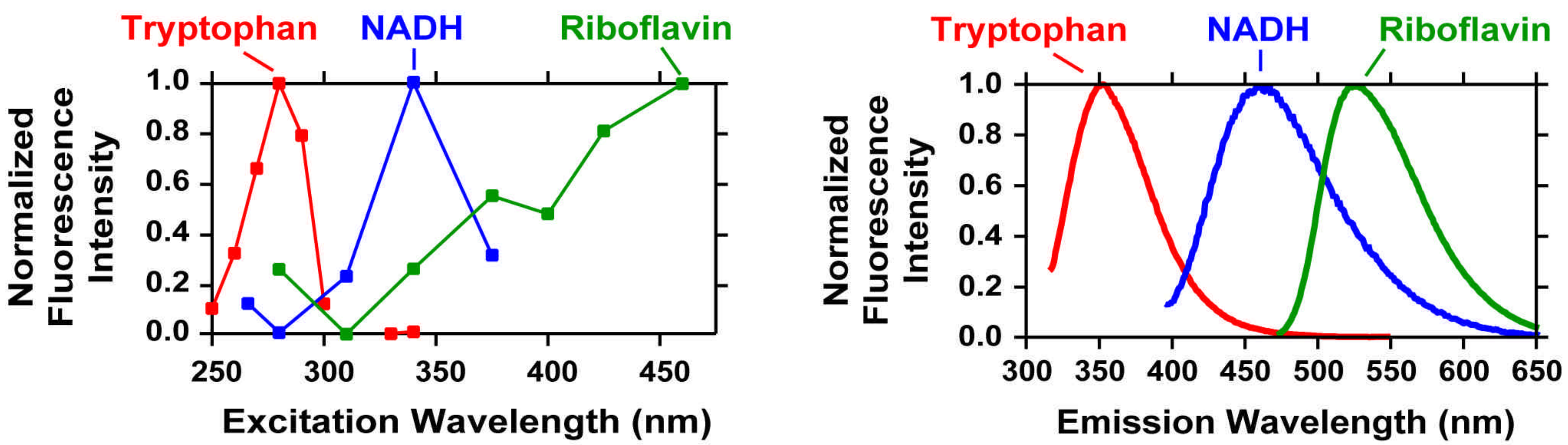
Biological Agent Sensor Testbed Performance Analysis

Performance Analysis

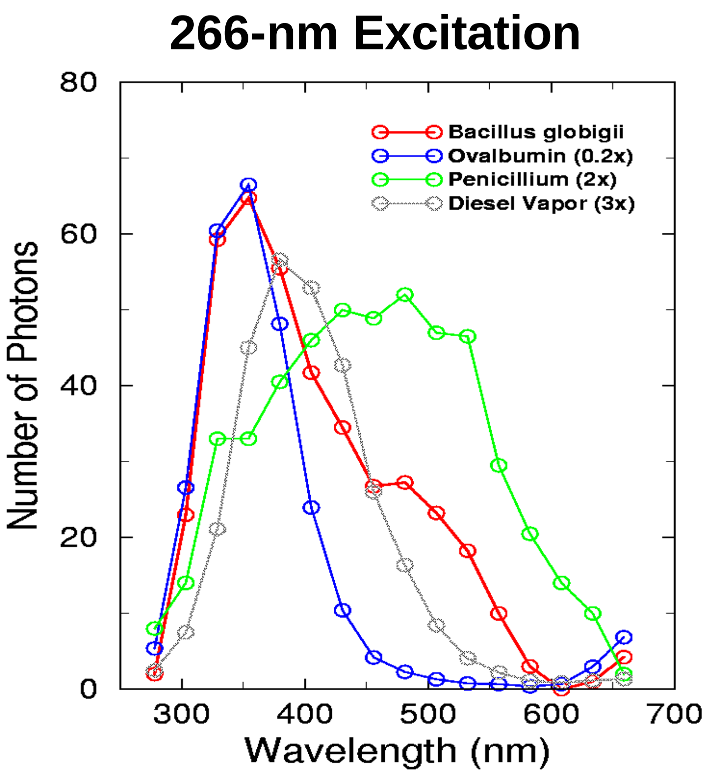
- **What LED wavelengths are optimal?**
  - **Detection**
  - **Discrimination**
- **What is the minimum detectable particle concentration?**
  - **LED power dependence**
  - **LED wavelength dependence**
- **Can particle size be determined from forward scattering?**
  - **Wavelength**
  - **Angular range of integration**
- **What happens at very high concentrations?**

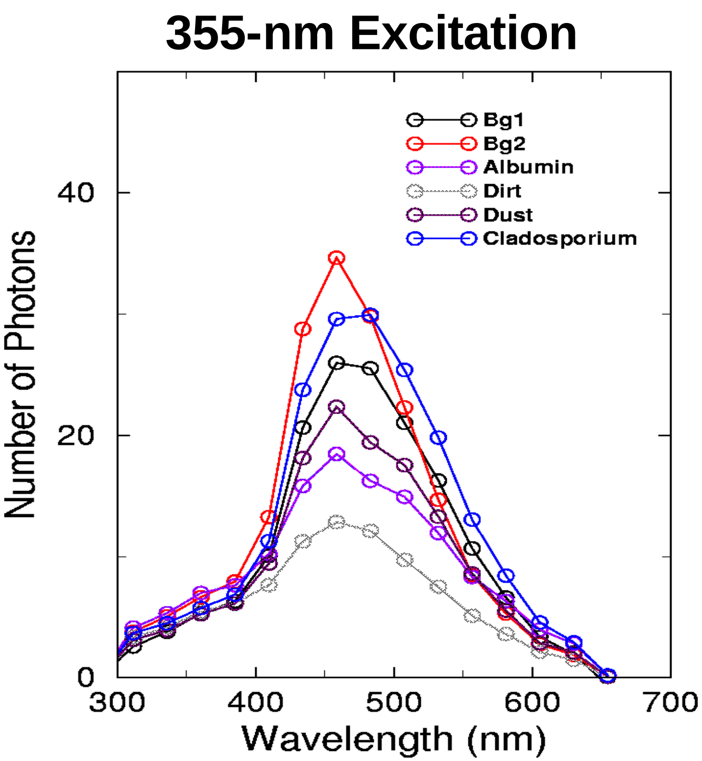
Bio-Fluorescence Spectra





Fluorescence Spectra





266-nm spectra provides more discrimination than 355 nm spectra.

Performance Equations

of detected photons

light power

illumination time

light wavelength

$$N_p = h_c h_d \frac{P t l}{A h c} s$$

cross-section

collection efficiency

detection efficiency

speed of light

Planck's constant

light cross-sectional area

# of detected particles

$$n = f C T$$

detection time

sample rate

particle concentration

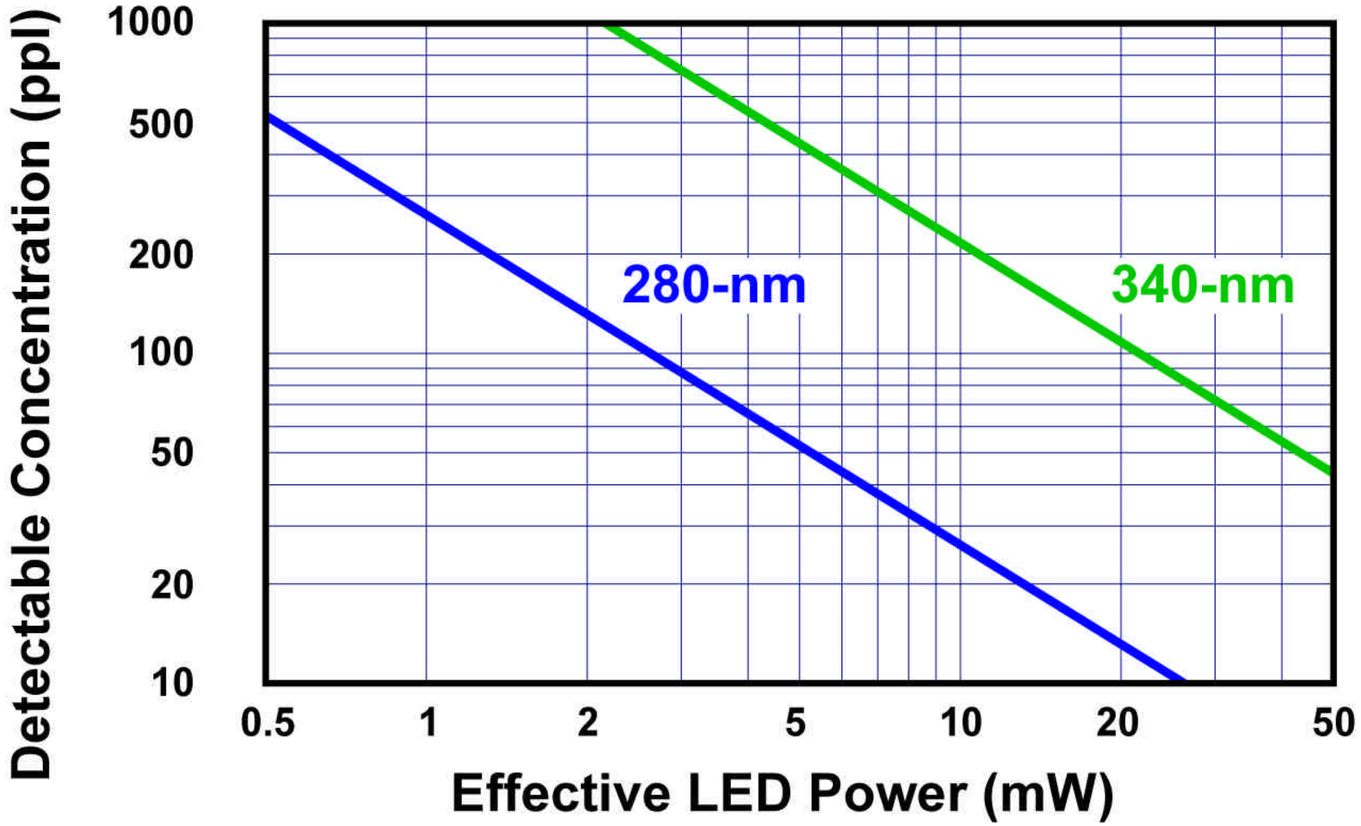
sample cross-sectional area

$$f = \frac{A L}{t}$$

sample length

sample transit time

Fluorescence Detection Analysis



Number of detected particles (N_b)	100 particles
Particle fluorescence cross-section (σ)	(50, 5) x 10^{-12} cm^2 @ (280, 340) nm
Number of detected photo-electrons (N_{pe})	100 photoelectrons
Photon collection, detection efficiency (η_d)	30% , 15%
Threat detection time (T)	60 s

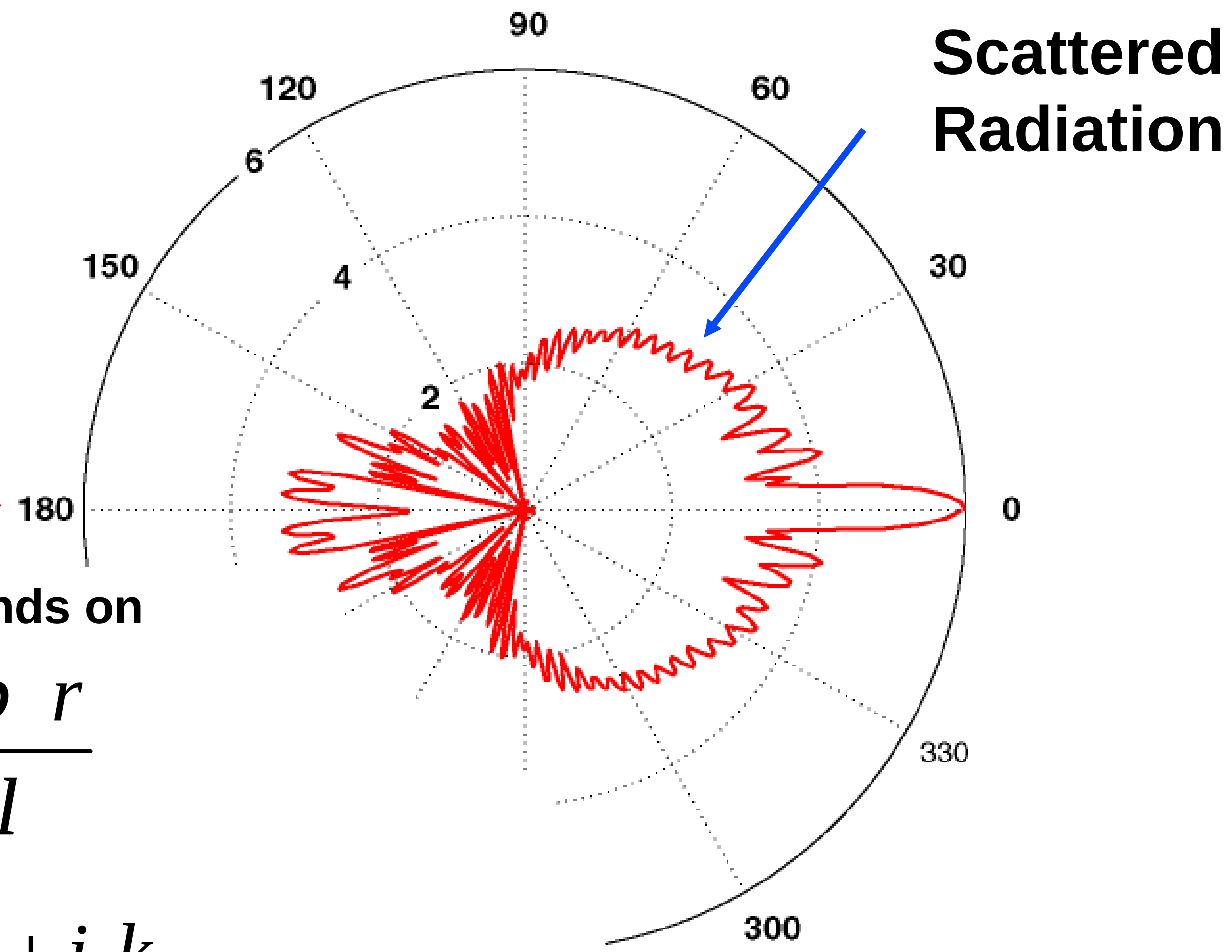
Example Calculation; 1-mm diameter LEDs

	elastic scattering	fluorescence	fluorescence
LED wavelength (cm)	2.80E-05	2.80E-05	3.40E-05
optical cross section (cm^2)	5.00E-09	5.00E-11	5.00E-12
LED diameter (cm)	1.00E-01		
sample cross-sectional area (cm^2)	4.00E-02		
Total Pulsed LED Power (W)	3.75E-03	3.75E-03	2.30E-02
Effective Pulsed LED power (W)	1.44E-03	1.44E-03	8.81E-03
photon collection efficiency	3.00E-01		
photon detection efficiency	1.50E-01		
illumination time, τ (s)	1.20E-03		
detected photons	1.36E+04	1.36E+02	1.02E+02
concentration uncertainty (ΔC/C)	1.00E-01		
number of detected particles	1.00E+02		
detection time (min)	1.00E+00		
sample length (cm)	2.00E-01		
sample rate (liter/min)	4.00E-01		
detectable concentration (ppl)	2.50E+02		

*** Sample volume = (2 x LED diameter)^3 = 8 x 10^{-6} liters**

Elastic Scattering Angular Distribution

Incident Radiation



Scattering behavior depends on

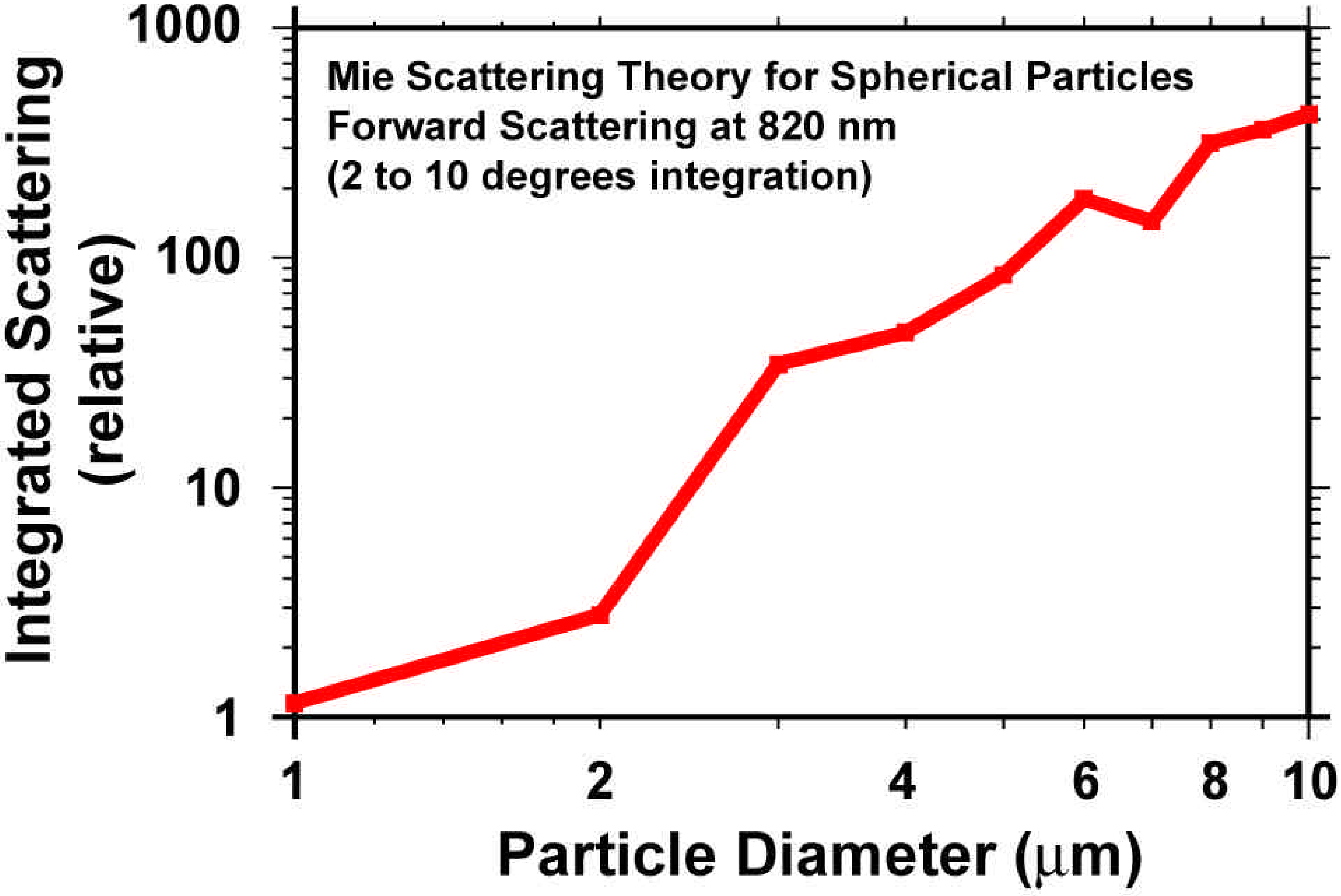
$$x = \frac{2\pi r}{\lambda}$$

and

$$n = n_r + i k$$

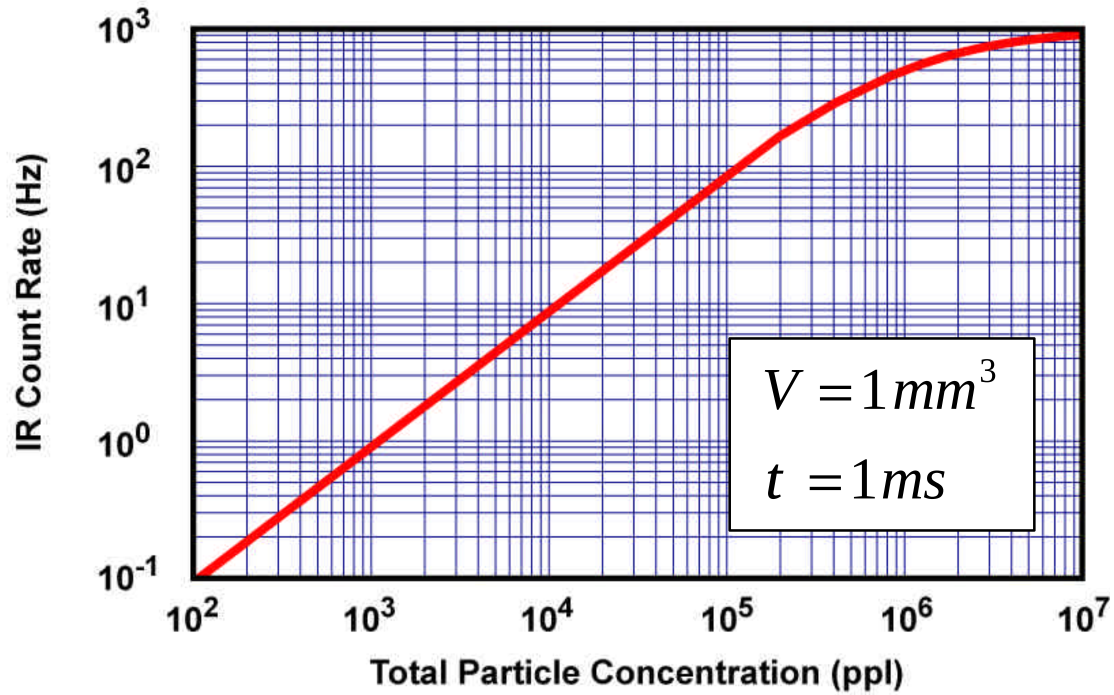
Barnett, D., The Mie scattering software is avalable at http://www.lboro.ac.uk/departments/el/research/optics/matmie/mfiles.html (May 2002).

Elastic Scattering and Particle Size



IR Particle Count Rate

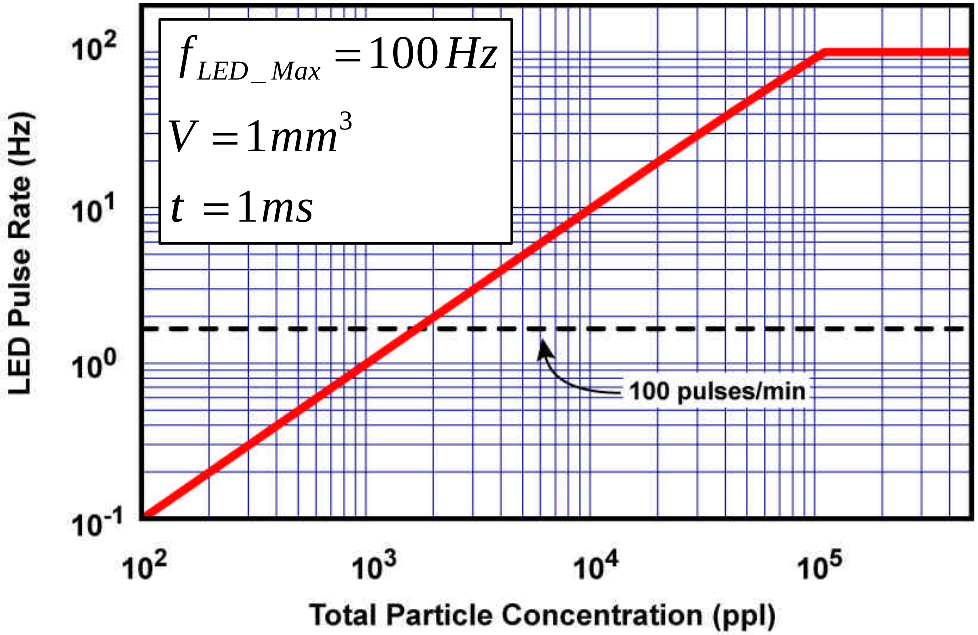
$$f_{IR} = \frac{\Phi C}{1 + \frac{\Phi C}{f_{IR\_\max}}} = \frac{1}{t}\left(\frac{V C}{1 + V C}\right); \; where \;\; \Phi = \frac{V}{t} \quad and \quad f_{IR\_\max} = \frac{1}{t}$$



LED Pulse Rate

$$f_{LED} = f_{IR} \qquad ; f_{IR} < f_{LED\_Max}$$

$$f_{LED} = f_{IR\_Max} \qquad ; f_{IR} \geq f_{LED\_Max}$$

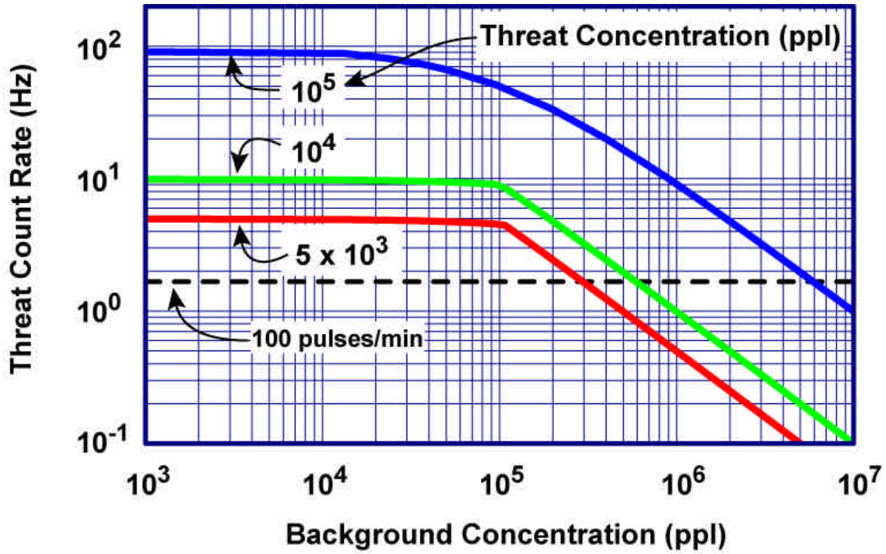


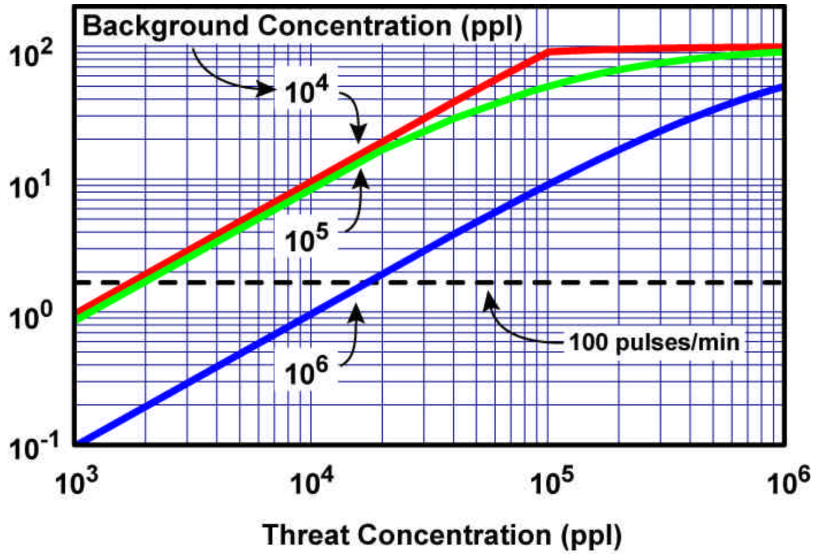
Threat Detection

$$f_{threat} = f_{LED} \frac{C_{threat}}{C}$$

C_{threat} = threat concentration
$C_{nonthreat}$ = nonthreat concentration
$C = C_{threat} + C_{nonthreat}$ = total concentration.

$$f_{LED\_Max} = 100Hz$$
$$V = 1mm^3$$
$$t = 1ms$$





Minimum Detectable Threat Concentration

$$C_{threat\_Min} = C_1 \quad for \;\; f_{LED} < f_{LED\_Max}$$

$$C_{threat\_Min} = C_2 \quad for \;\; f_{LED} = f_{LED\_Max}$$

or

$$C_{threat\_Min} = Max[C_1, C_2]$$

where

$$C_1 = \frac{\frac{1}{V} + C_{nonthreat}}{\frac{1}{t \;\; f_{alarm}} - 1}$$

and

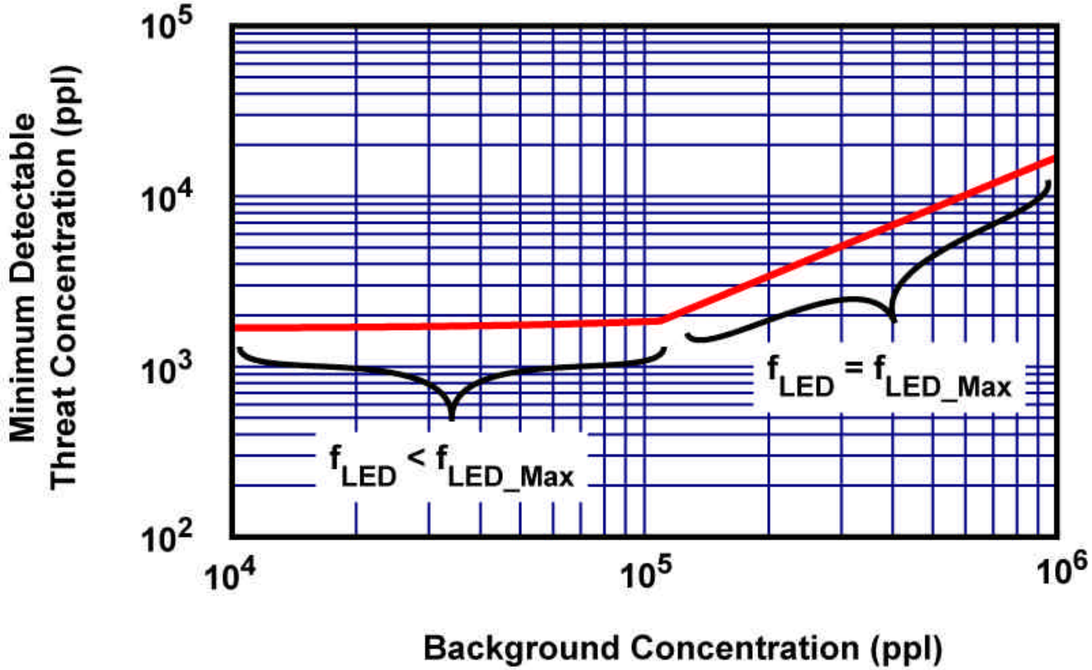
$$C_2 = \frac{C_{nonthreat}}{\frac{f_{LED\_Max}}{f_{alarm}} - 1}$$

$$f_{alarm} = 1.667 Hz = 100/\min$$

$$f_{LED\_Max} = 100\,Hz$$

$$V = 1mm^3$$

$$t = 1ms$$

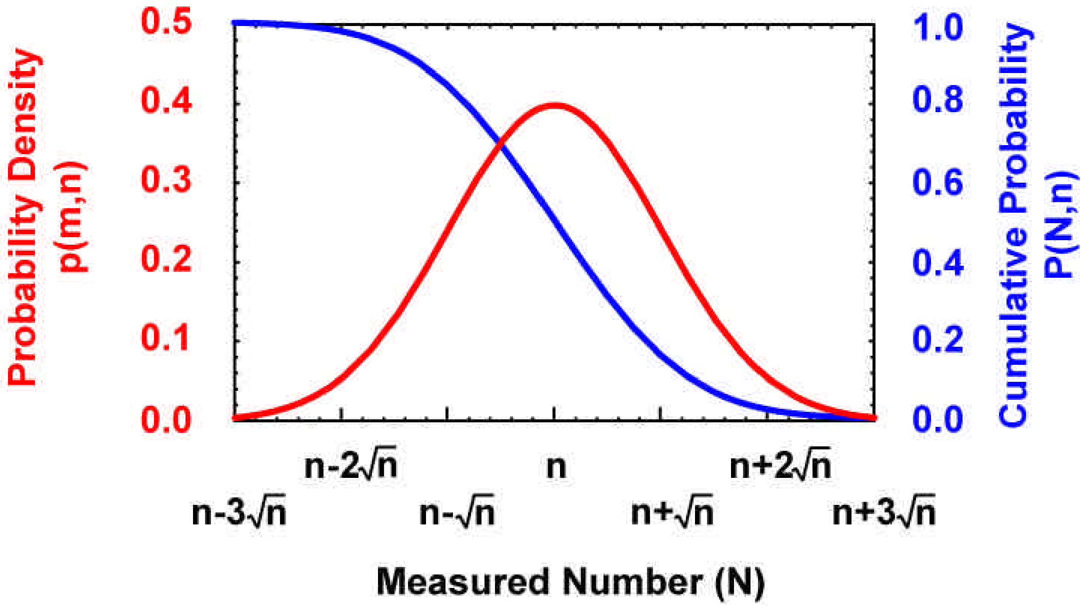


Detection Probability, P_d

Cumulative probability of counting N or more particles when the average count is n particles

$$P_d(N,n) = \int_N^\infty p(m,n)\,dm = \int_N^\infty \frac{e^{-\frac{(m-n)^2}{2n}}}{\sqrt{2p\,n}}\,dm$$

n >> 1, m >> 1



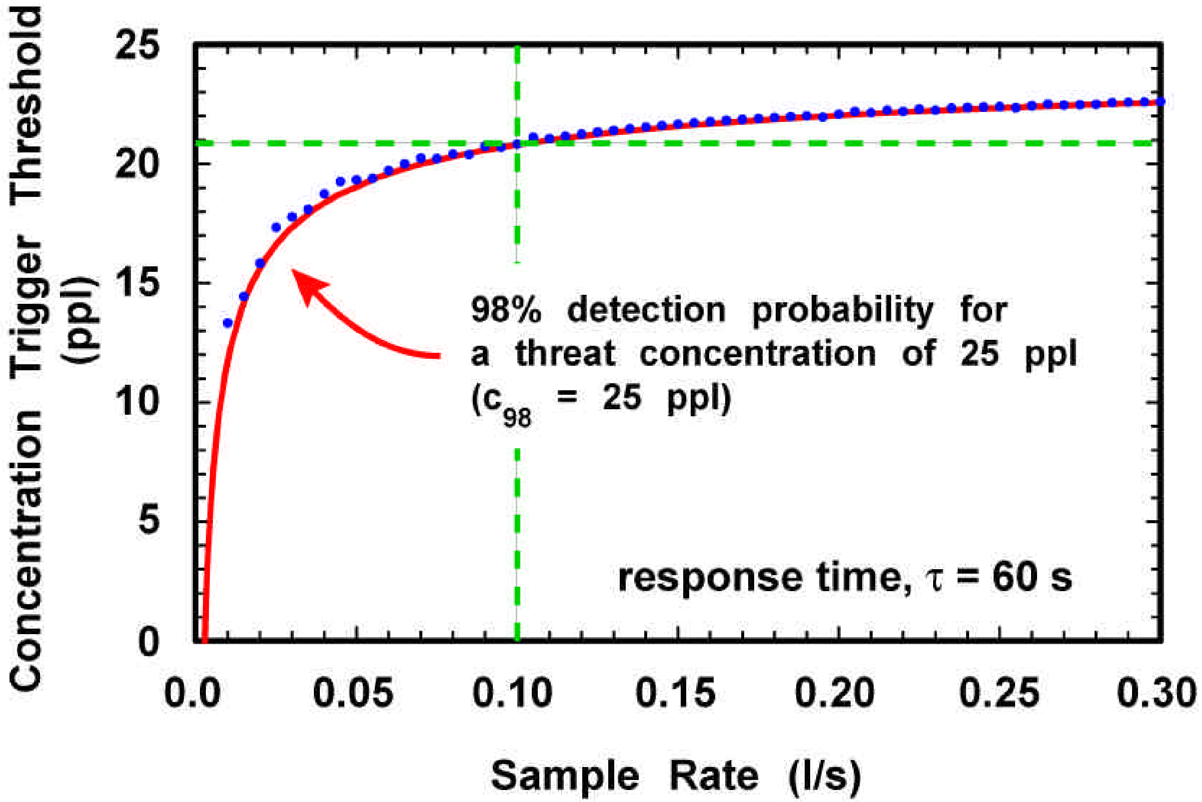
$$P_d(N,n) = 0.98,\ for$$

$$N = n - 2.05375\sqrt{n}$$

$$where: n >> 1$$

Concentration Trigger Threshold

$$c_T = c_{98}\left(1 - \frac{2.05}{\sqrt{c_{98}\, f\, t}}\right)$$



Summary

- **This analysis shows that given currently available UV LEDs it should be possible to detect biological agent aerosols at concentrations of interest.**

- **This analysis also shows how particle triggering can result in nonlinear threat detection**
  - **It is also possible to use this analysis to correct the measured threat concentration using the background concentration**

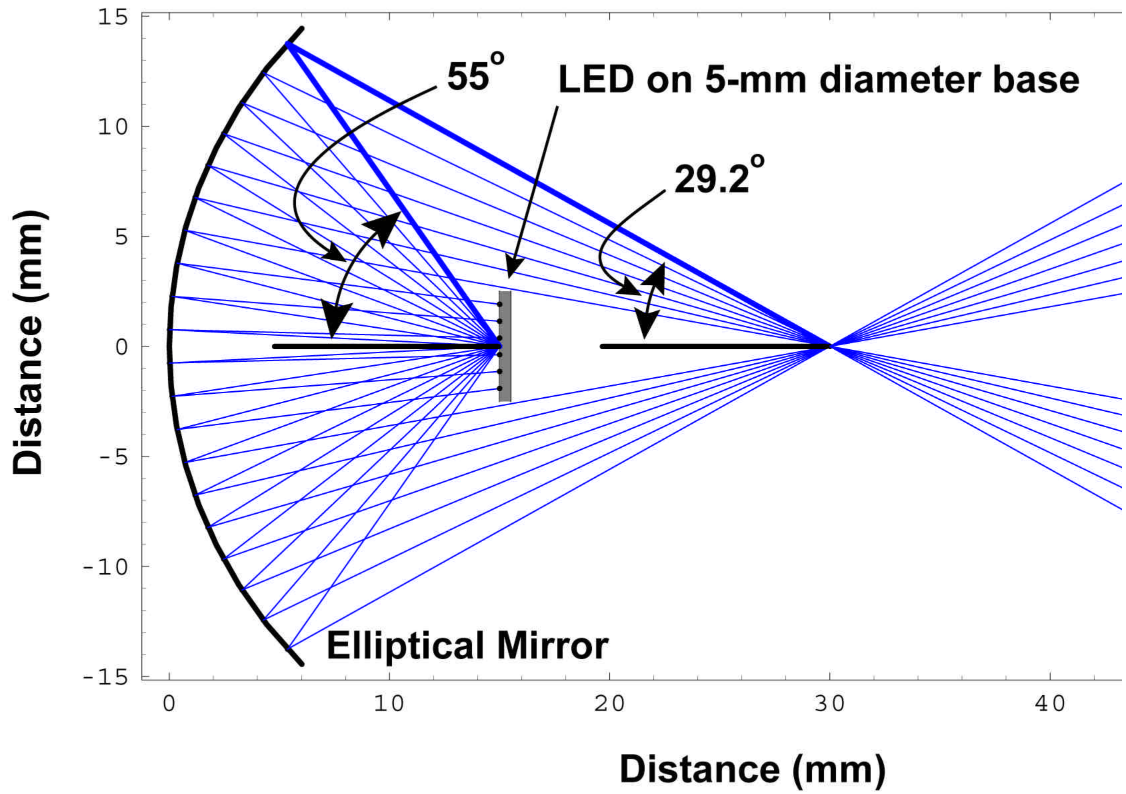
- **High probability of detection requires setting the concentration detection threshold below the mean concentration of interest.**

Biological Agent Sensor Testbed
Optical Design

Challenges

- Collect LED light efficiently
  - Re-image LED light into sample volume
- Mount LED with good heat sinking
- Collect signal light efficiently
- Utilize two LED wavelengths
- Measure particle size
- Avoid particle concentrator
  - Need large sample volume
- Keep optics clean
- Utilize low cost optical components and mounts
  - Design optical system with minimum of optical adjustments

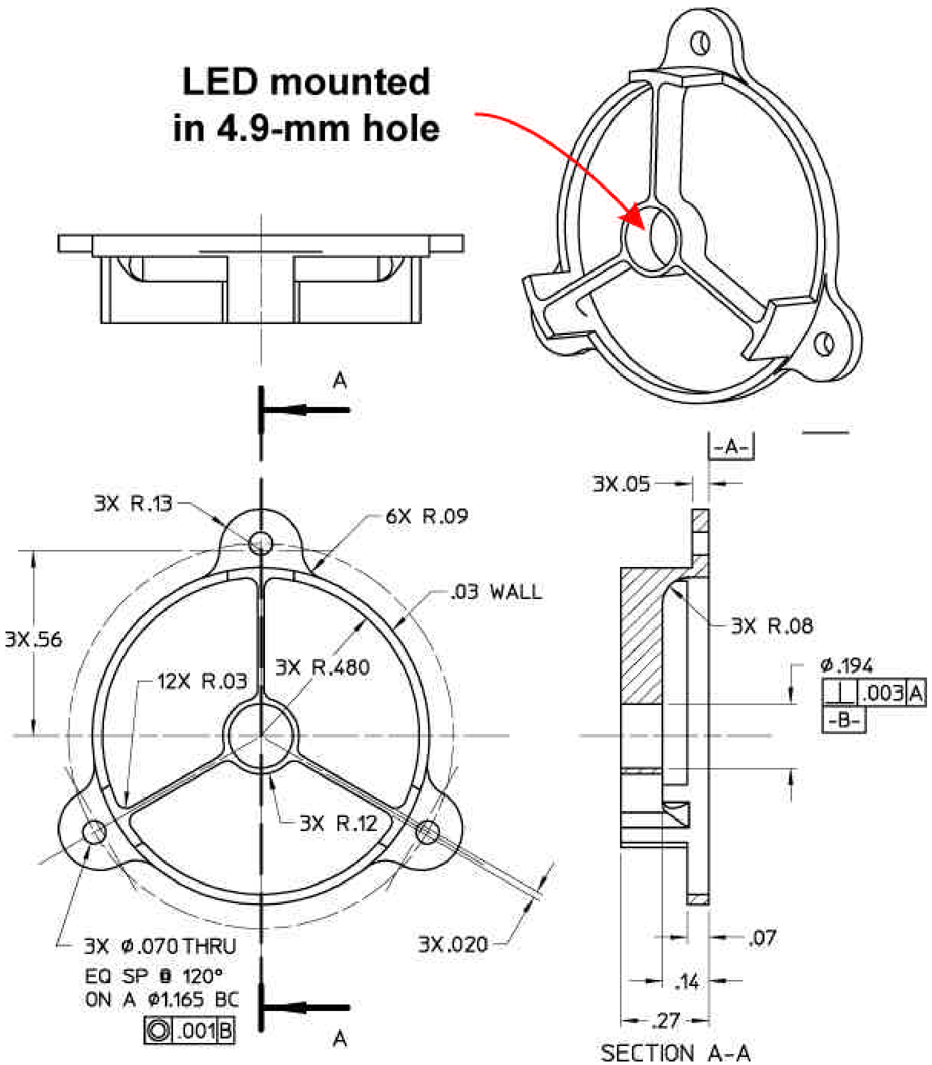
LED Light Collection Mirror

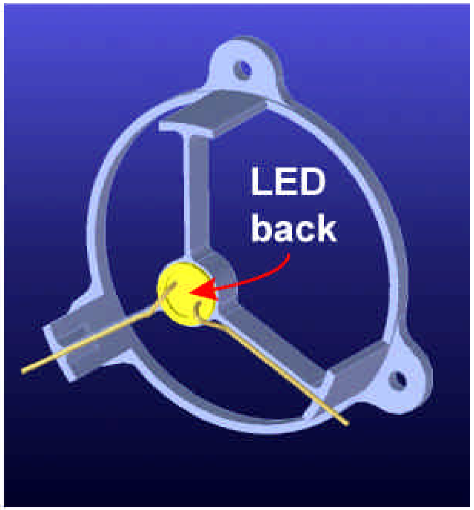


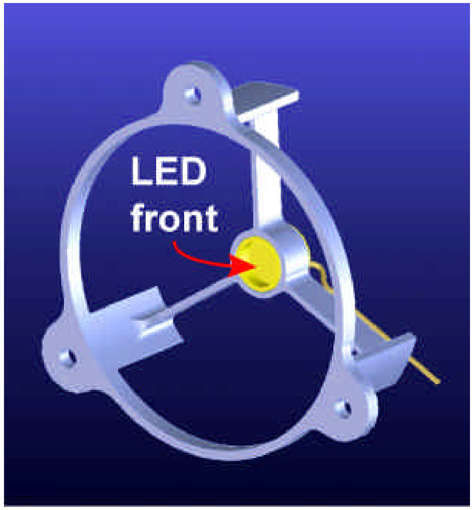
Magnification	2
Mirror to LED	15 mm
Mirror to image	30 mm
Mirror diameter	27.51 mm
Mirror depth	5.37 mm
Mirror semi-major axis	22.5 mm
Mirror semi-minor axis	21.21 mm
LED mount diameter	7 mm
Source divergence	55^0
Source obscuration	25^0
Image divergence	29^0
Image obscuration	13^0
LED light collection efficiency	67% - 18% = 49%

Elliptical mirrors made by Opti-Forms, Inc.

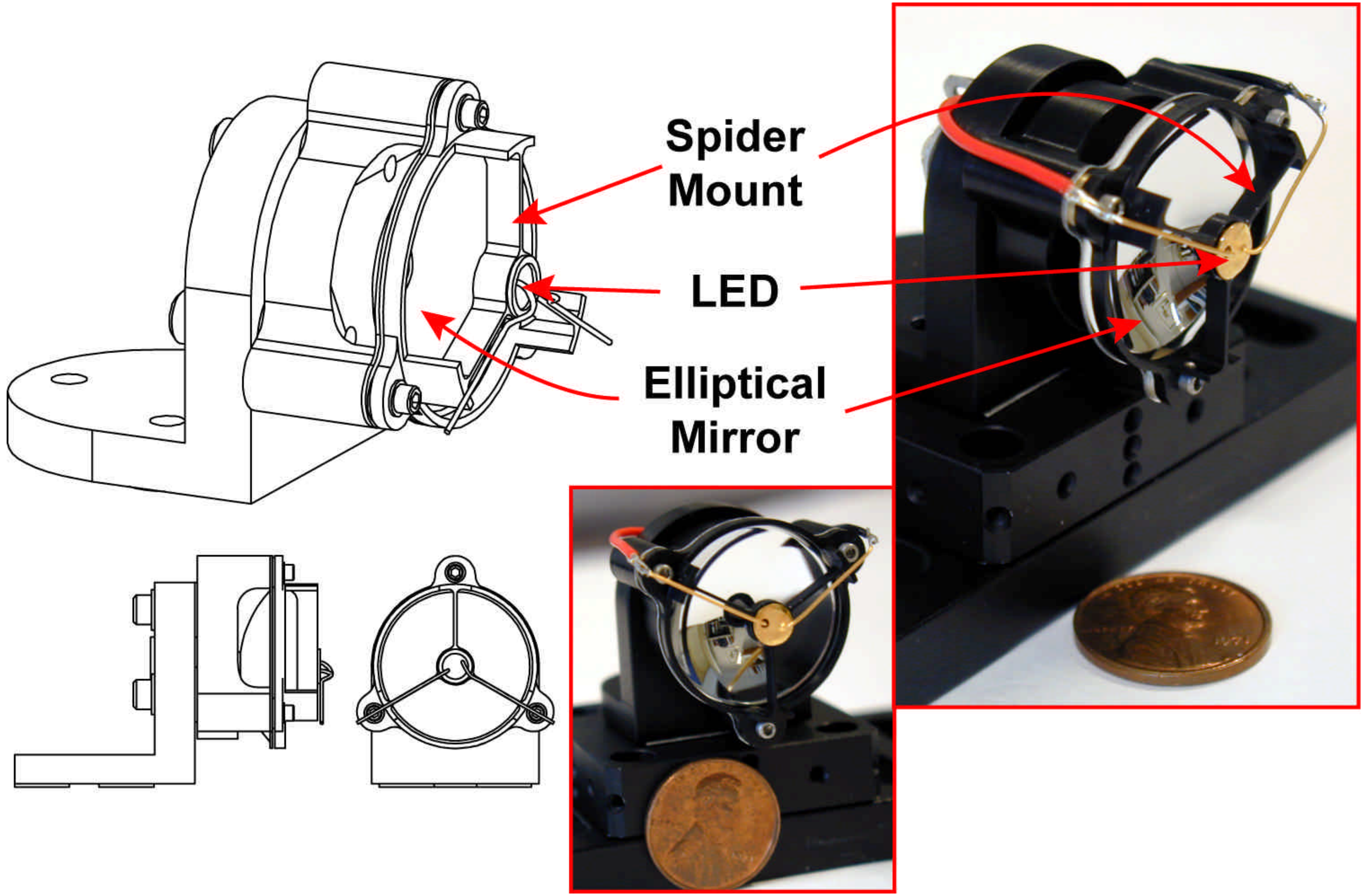
LED "Spider" Mount



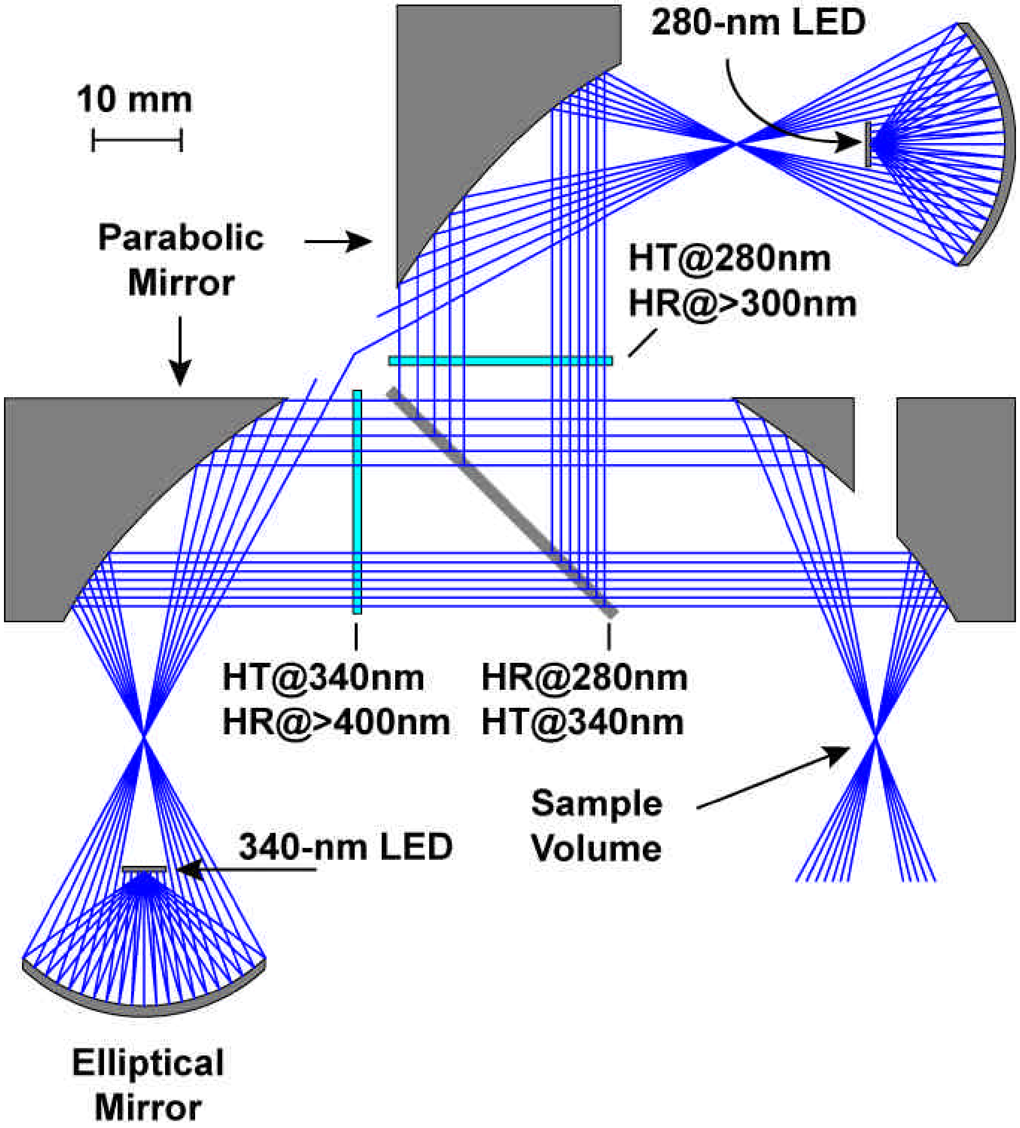




LED Mount and Elliptical Mirror

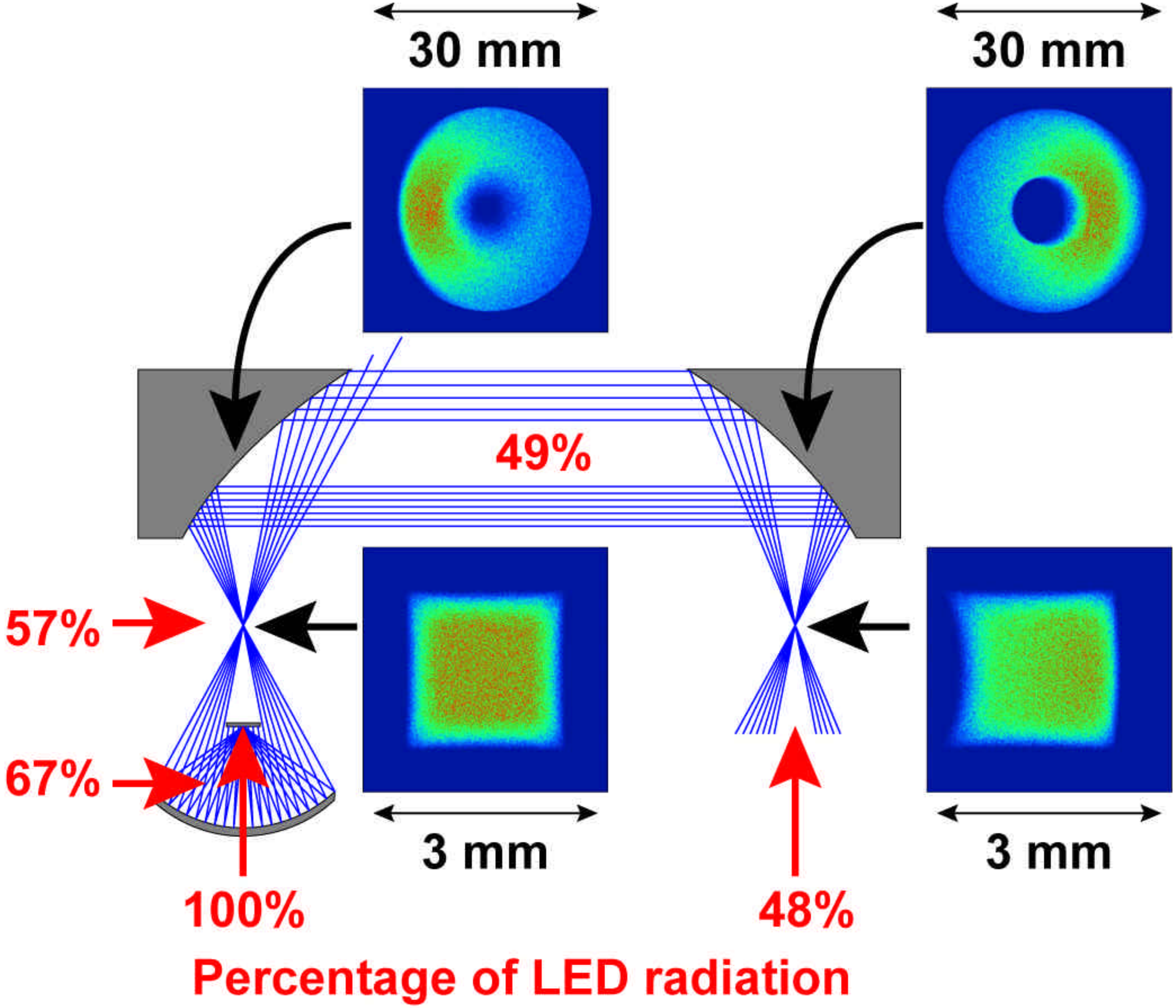


LED Optics

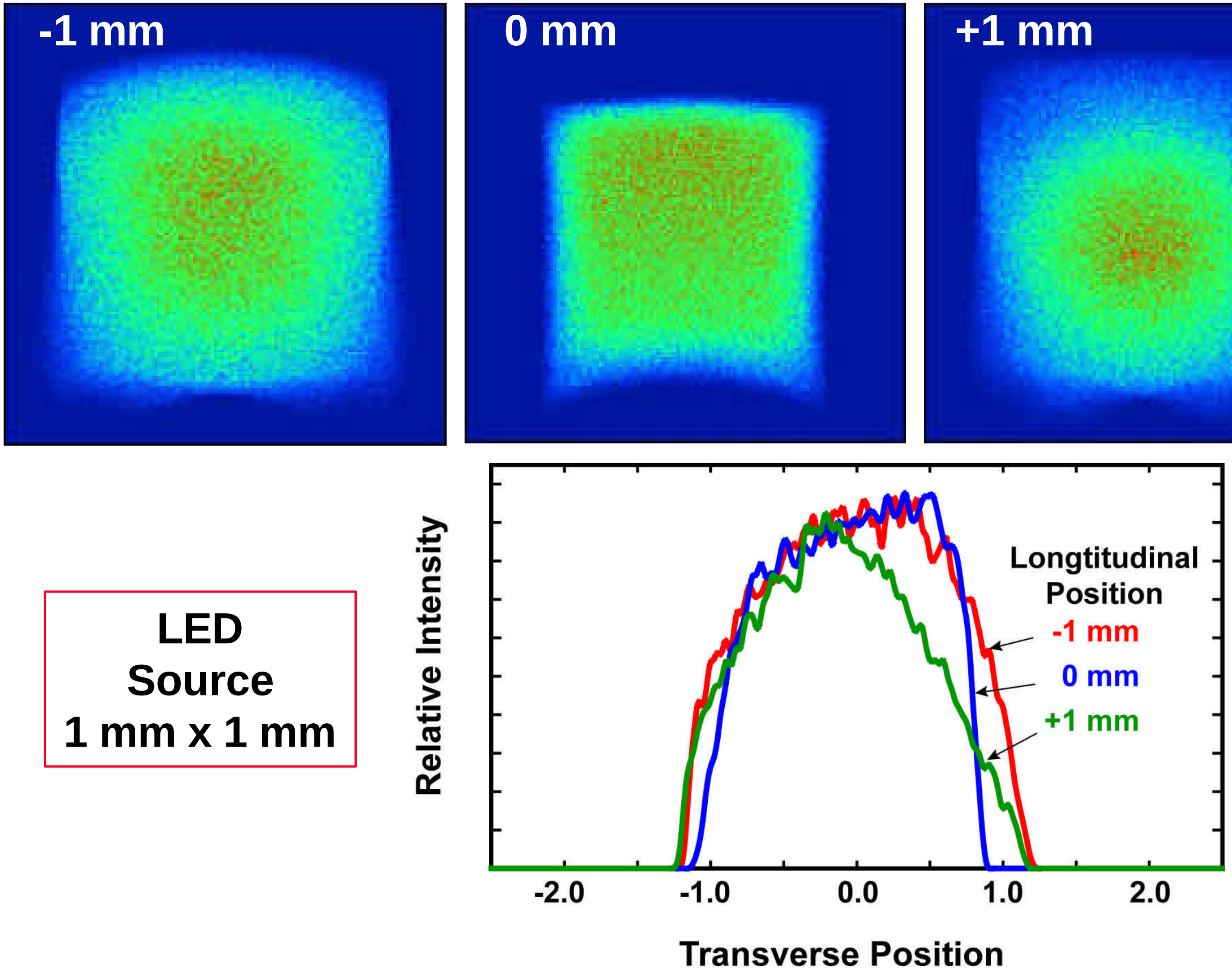


LED diameter = 1 mm
Sample Diameter = 2 mm
Sample Length = 2 mm
Sample Volume = 8 mm^3
Transit time = 1.2 ms
Sample Rate = 0.4 l/min

Calculated Imaging of 1-mm LED into Sample Volume

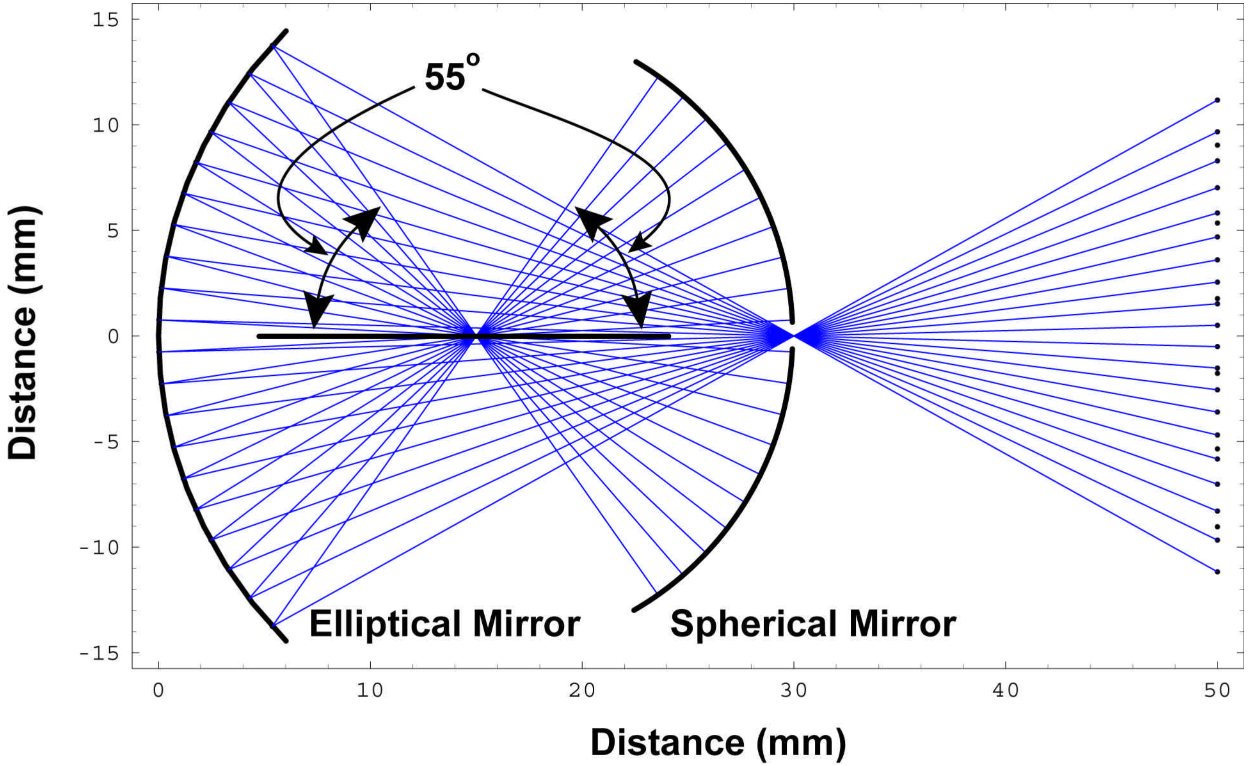


Calculated LED Image Quality in Sample Volume



LED
Source
1 mm x 1 mm

Signal Collection Mirrors



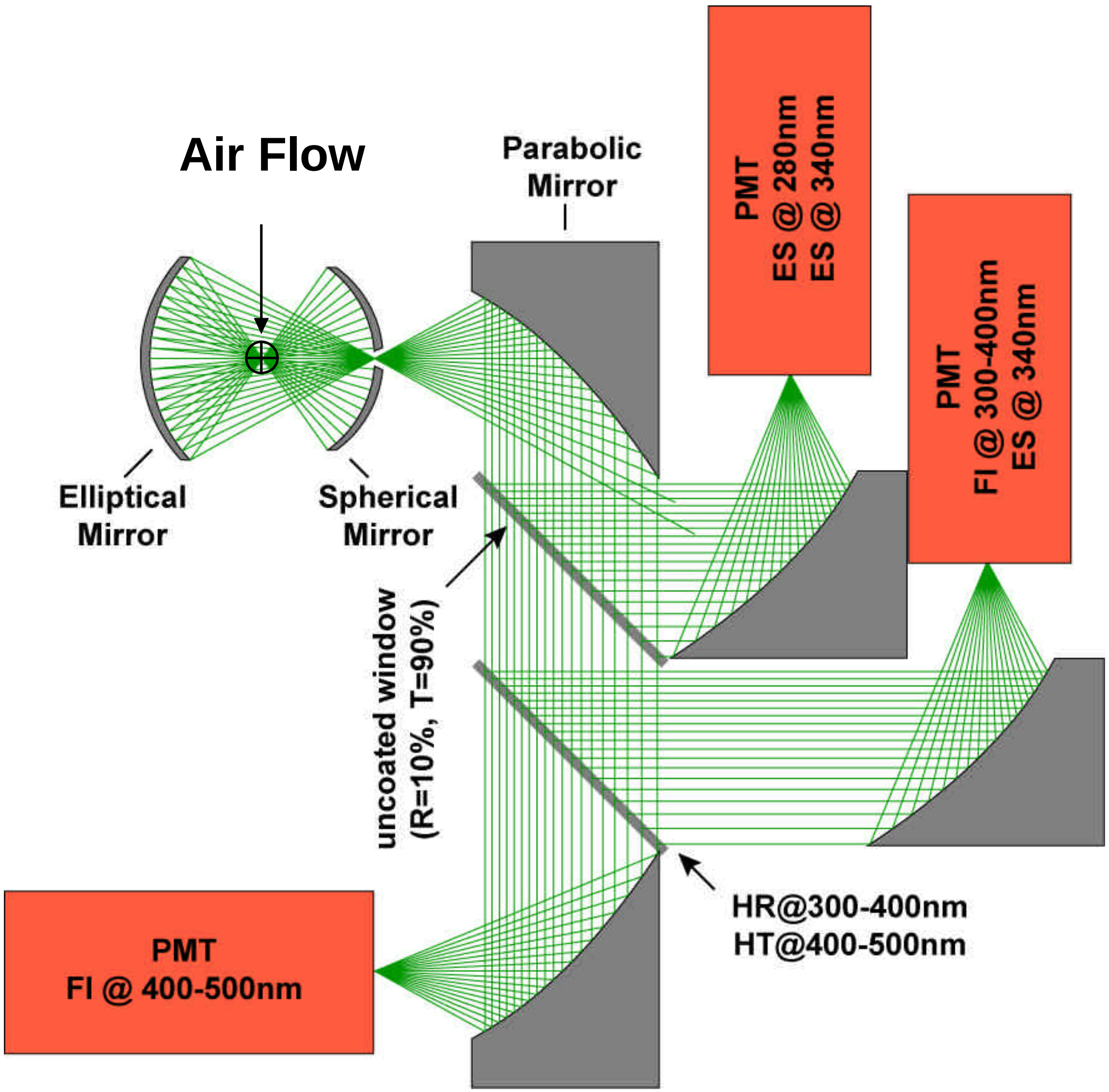
Collection efficiency = 42%.

The elliptical mirror is the same as the LED light collection mirror.

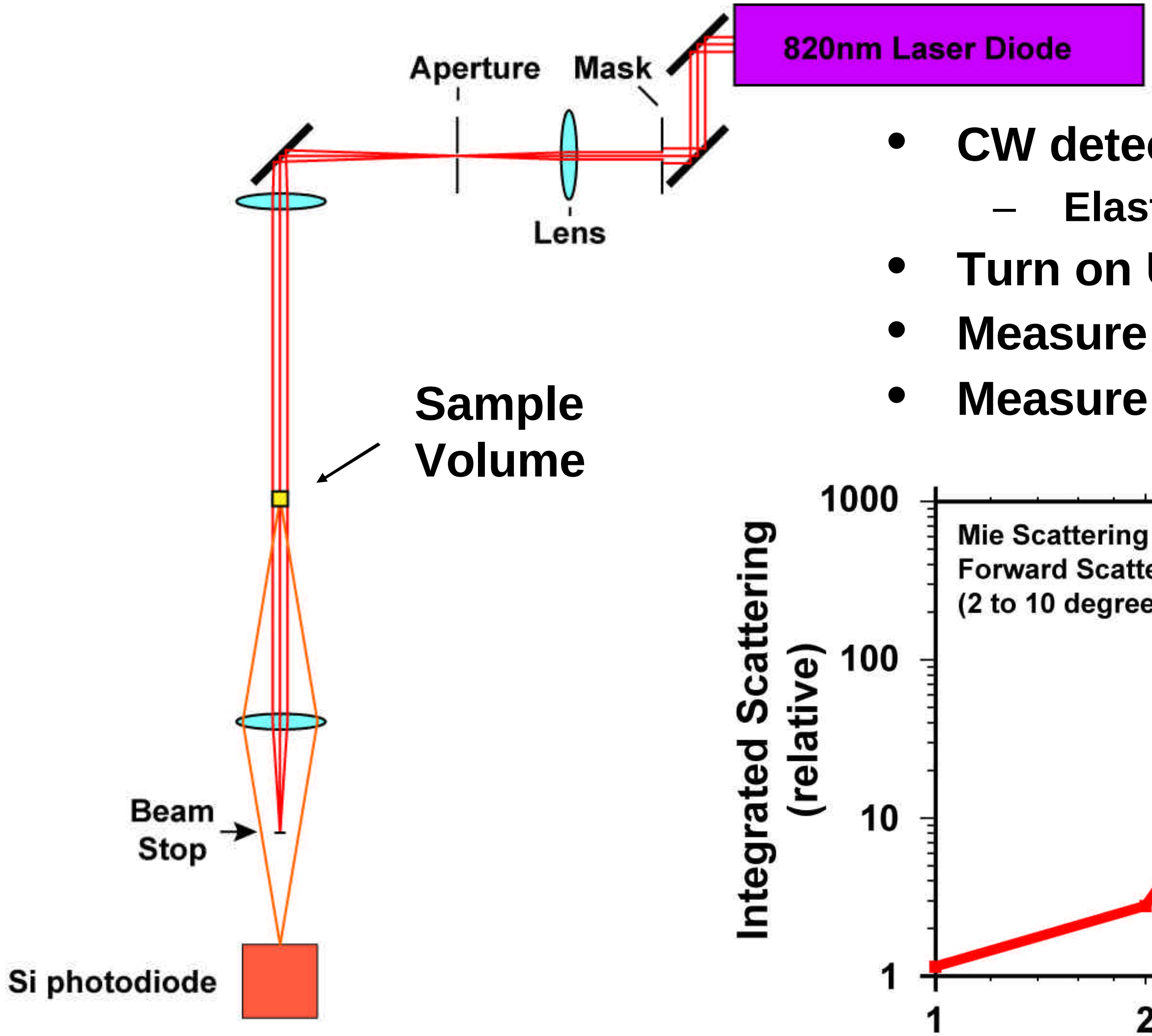
The spherical mirror has a radius of curvature of 15 mm.

The spherical mirror has a diameter of 25 mm.

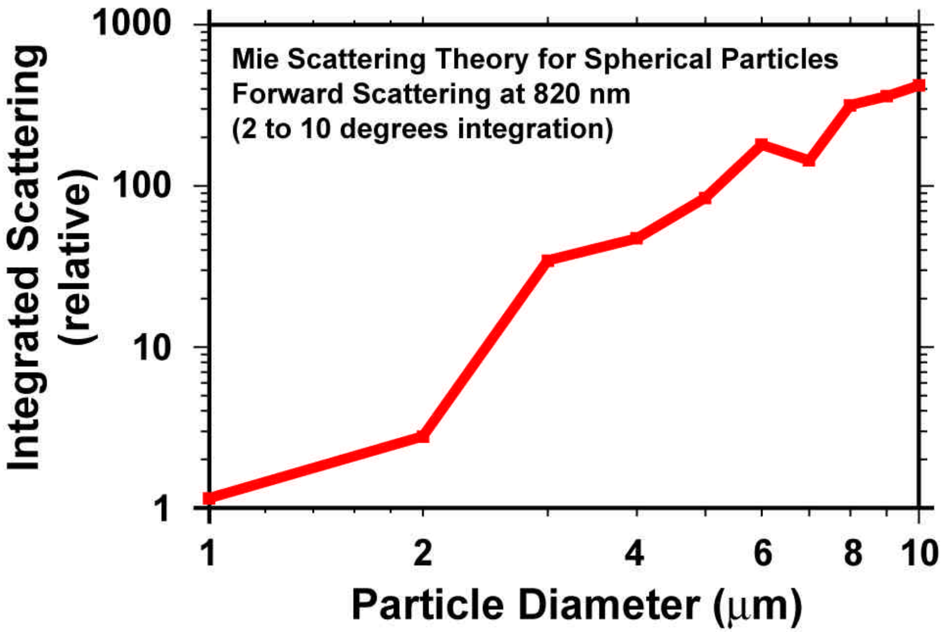
Signal Optics



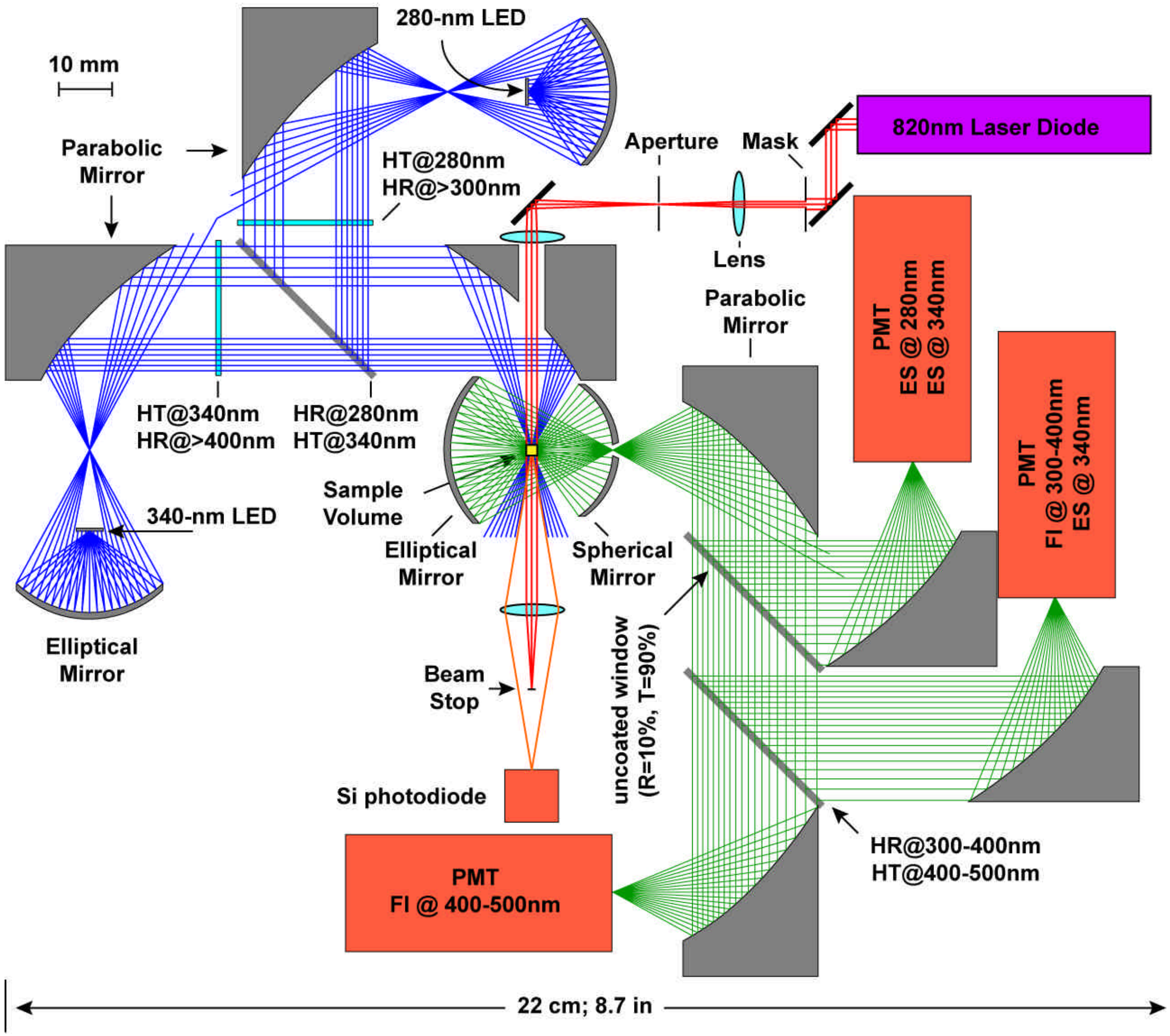
IR Laser Diode



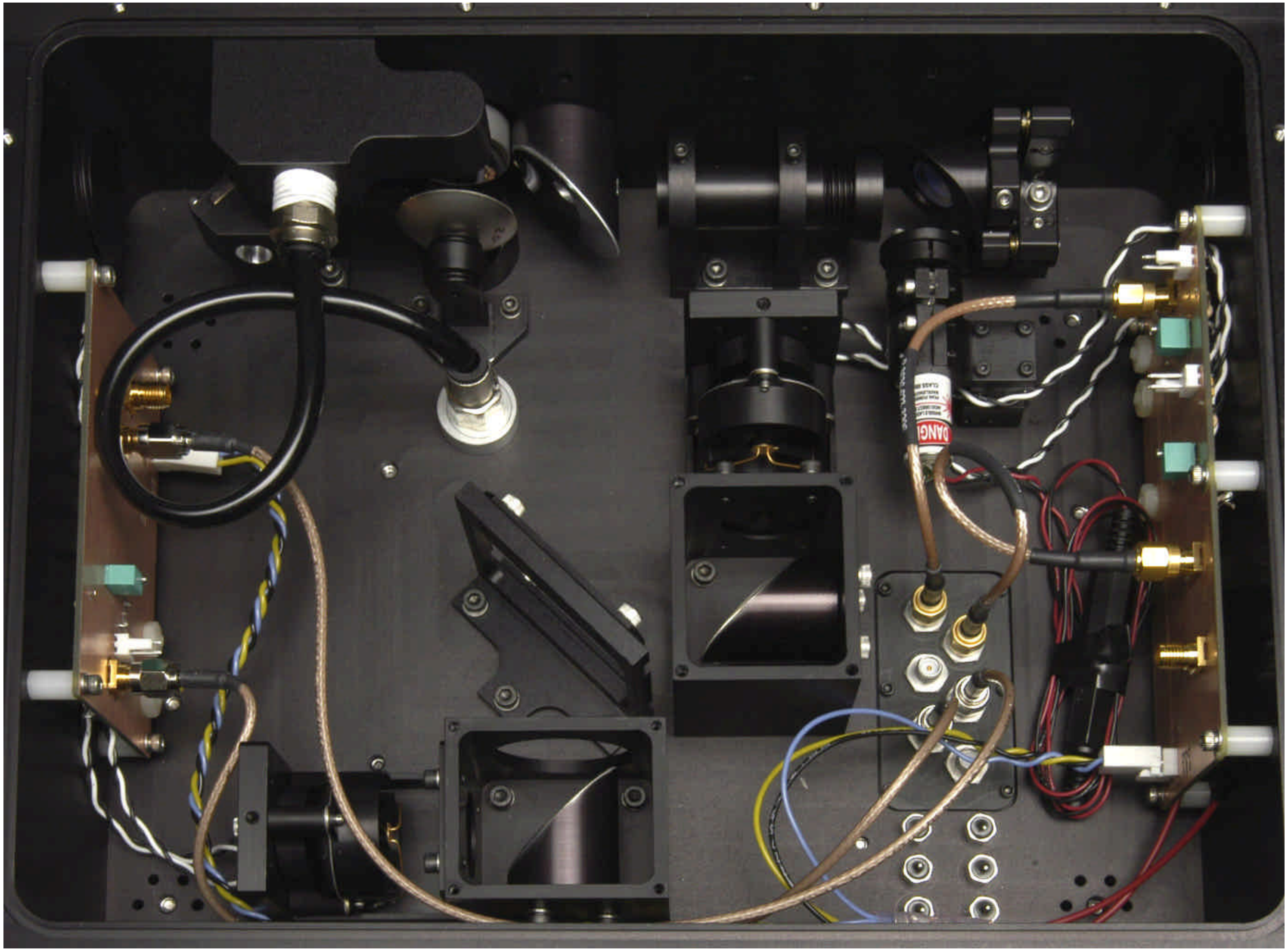
- CW detection of particles
  - Elastic scattering
- Turn on UV LEDs
- Measure particle size
- Measure air speed



Combined Optics



EDU Optics Chamber



EDU PMT Chamber

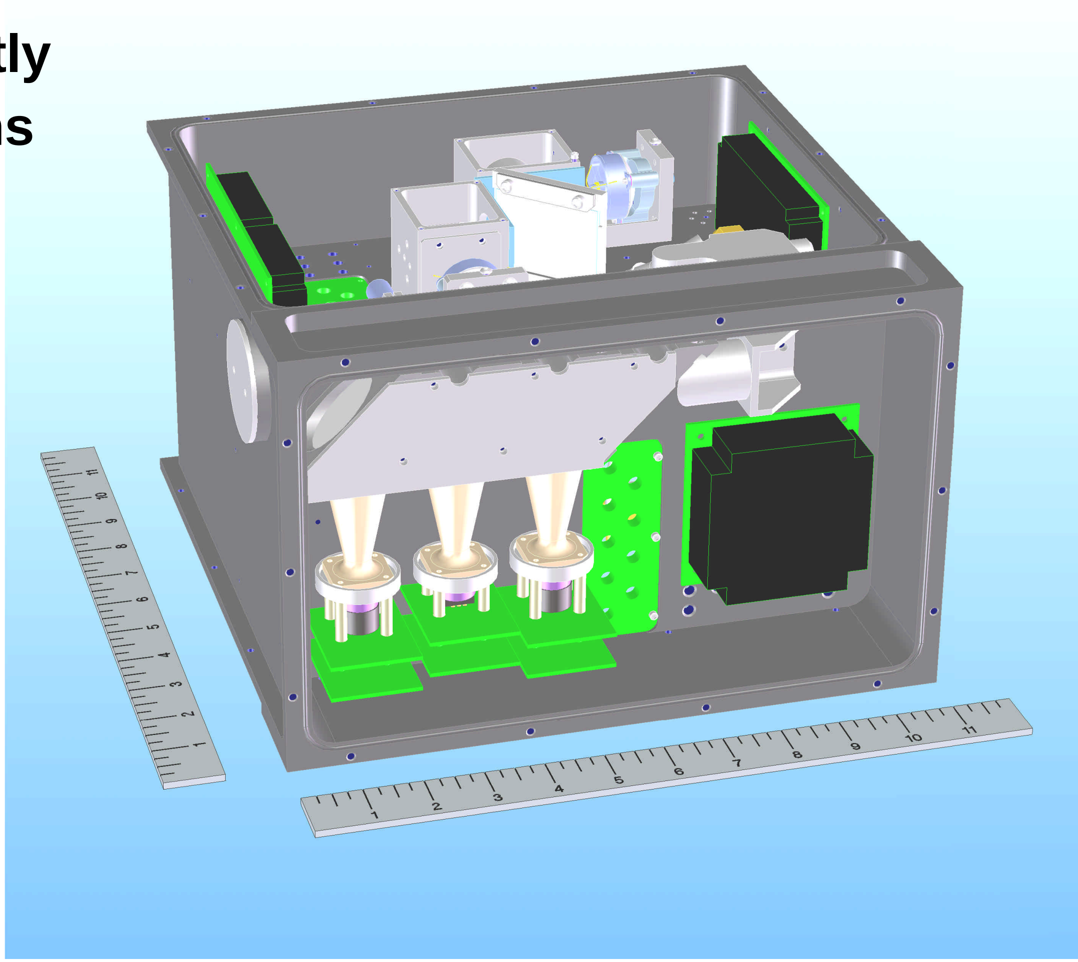
Summary

- High efficiency optical system
  - 50% LED light collection efficiency
  - 40% signal light collection efficiency
- LEDs mounted on good heat sinks
- Optical system has minimal distortion
  - Retains flat top intensity of LED in sample volume
- IR forward scattering sizes particles.
- Large sample volume
  - No concentrator needed
- Compatible with clean-optics air flow design

Biological Agent Sensor Testbed Mechanical Design

Mechanical Design

- Collect LED light efficiently
- Collect signal light efficiently
- Utilize two LED wavelengths
  - LED modulation
  - PMT gating
- Keep optics clean
  - Confine sample air flow
- Small size, low weight, low power
- Low cost
  - LEDs
  - Everything else



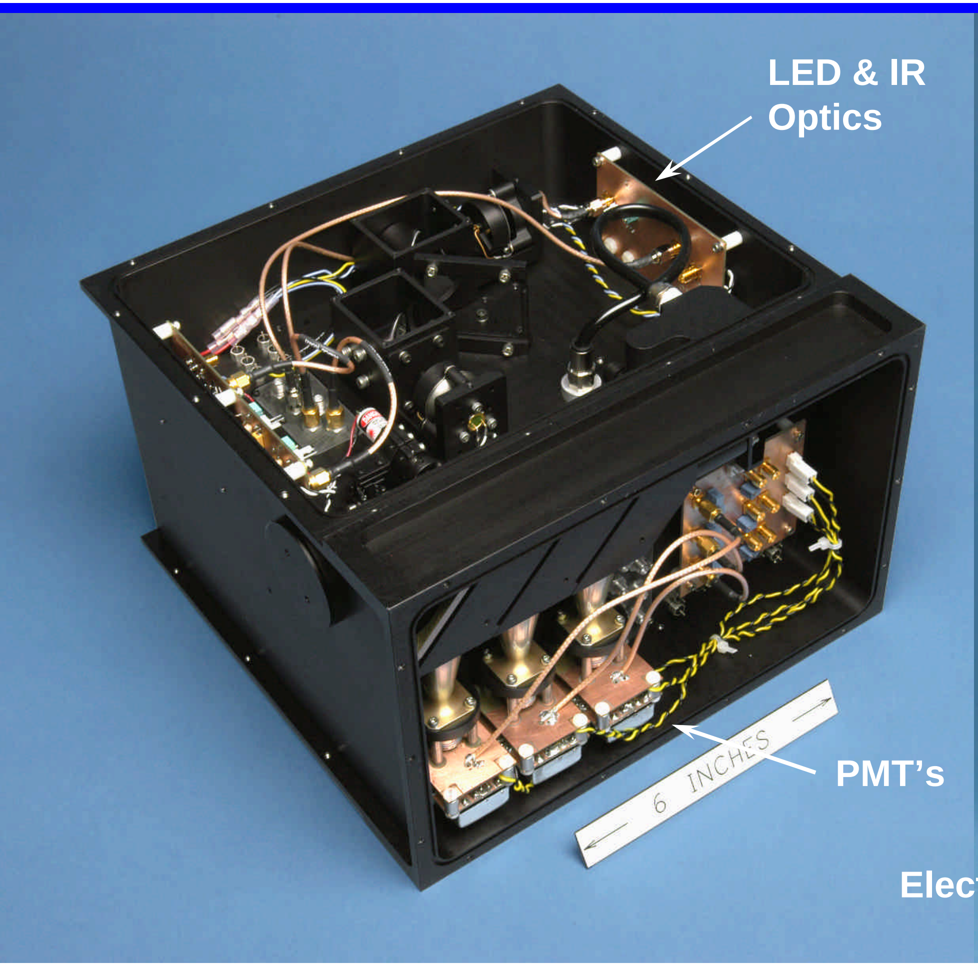
Mechanical Systems

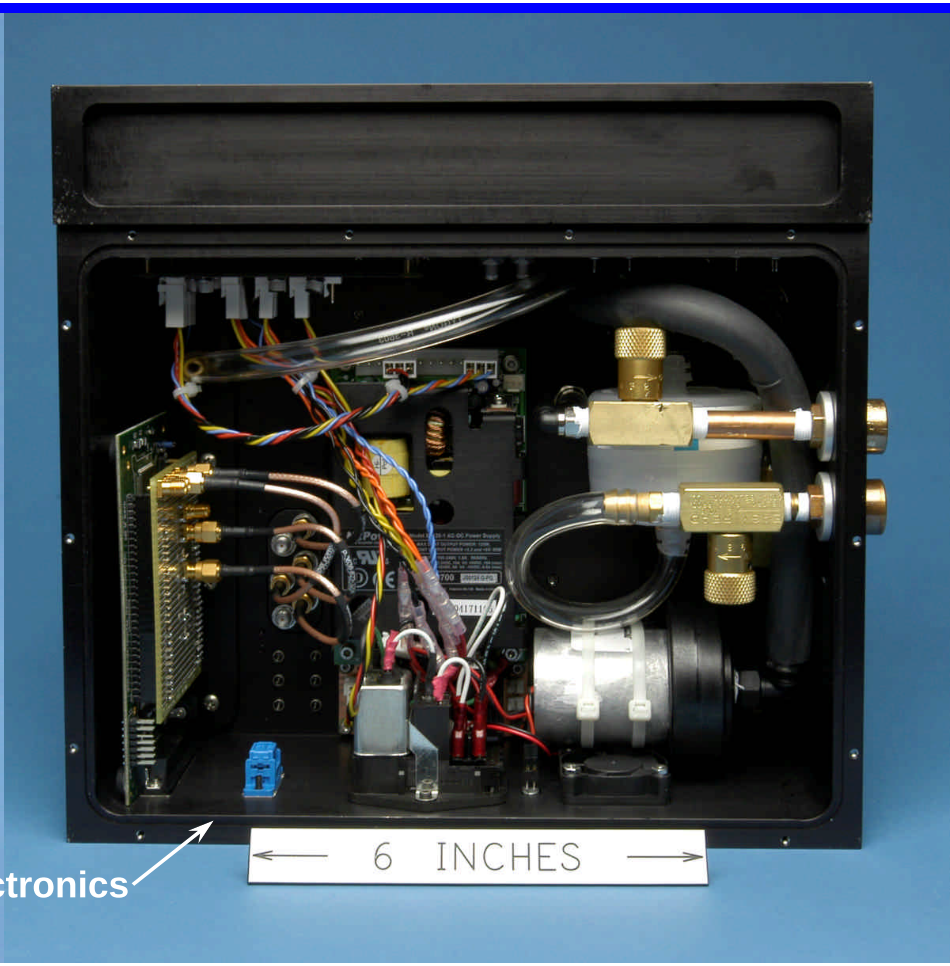
- **Housing**
- **Airflow System**
  - Requires a non-turbulent steam of air to be sampled
  - It is a “Suck-Thru” system, with control valves on Sample & Make-up air inlets
    - Simple “set and forget” control
  - Filtered make-up air
    - Makeup air delays turbulence of jet
    - Maintains cleanliness of optics
- **IR Triggering system**
  - Forward scatter of IR laser light off particles in sample volume is used to trigger the LED’s
    - Extends the life of the LED’s
    - Provides particle size information
    - Also triggers the data collection system

Mechanical Systems con't.

- **LED light sources to illuminate particles**
  - 340 nm and 280 nm light sources to alternately illuminate the sample volume
    - Light sources are optically co-aligned and filtered while collimated
    - Designed optical mounts to be as self aligning as possible for a EDU
- **Scattered and Emitted light collection**
  - Light from particles in the sample volume is collimated and then wavelength separated to three PMT's
  - Elimination of stray light from LED sources is extremely important

SUVOS/BAST Housing

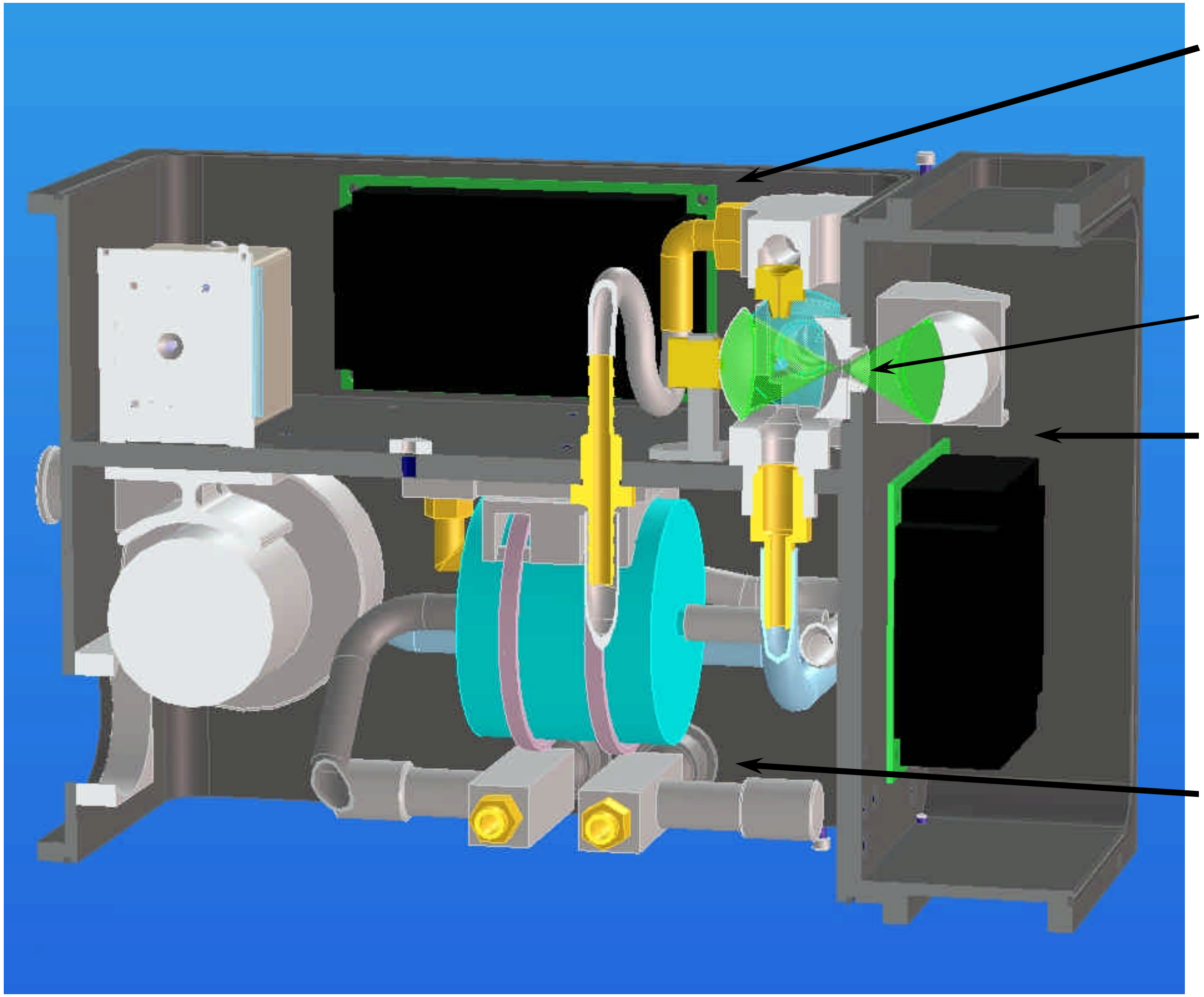




Designed to be compact
Divided into three compartments
Provides easy access to all compartments

Weight approx. 17.5 lbs
11.1" x 10.9" x 7.3"
Can be used in any orientation

Cross Section Through Housing

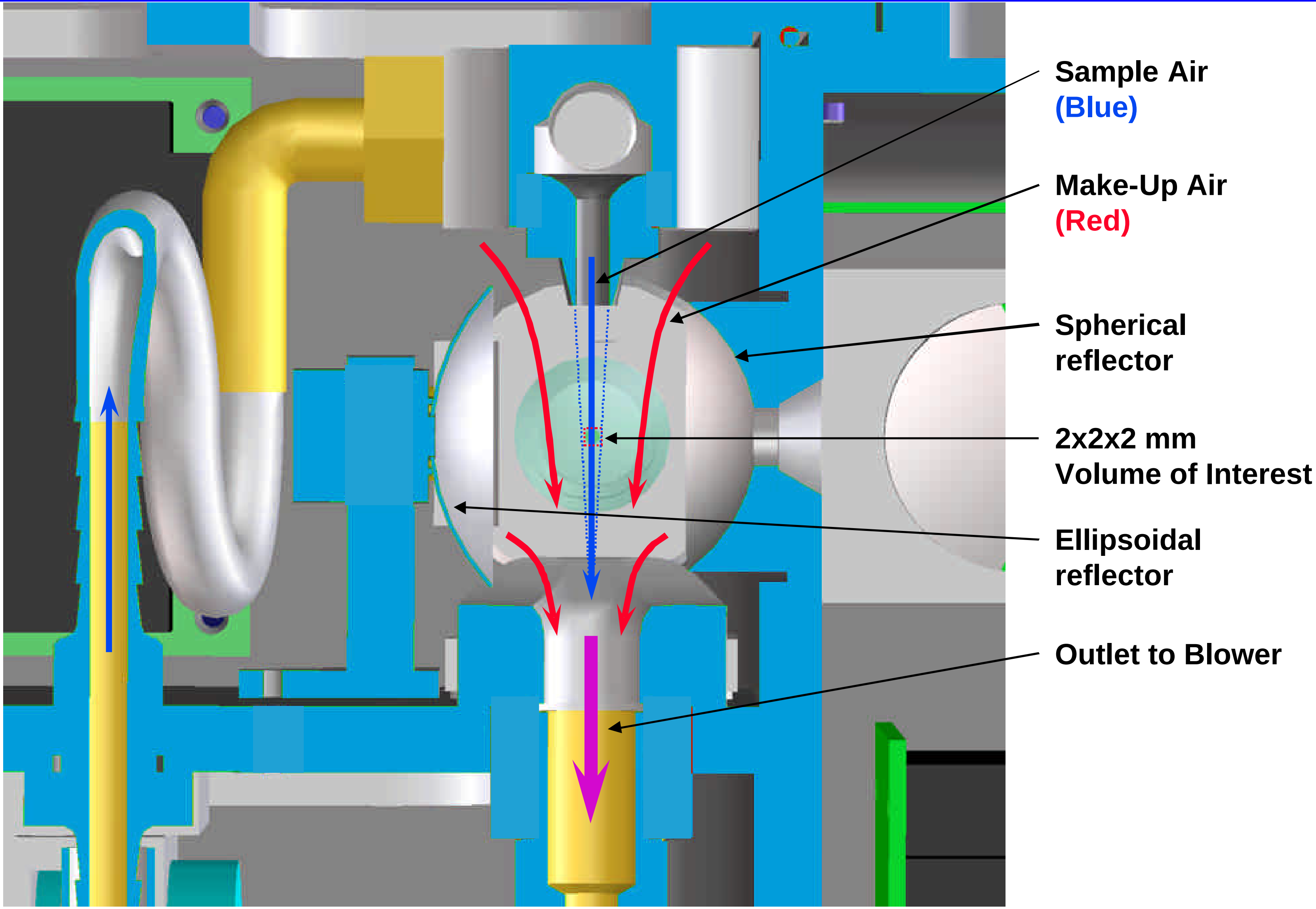


Upper Optical Compartment – Houses LED's and IR Scatter Detector
- Light-tight
- Airtight (except for Inlets & Outlet)
- Maintains cleanliness of optics
- Only open to PMT Compartment at Sample Chamber Opening

PMT Compartment
- Light-tight
- Airtight
- PMT's are away from stray light
- Keeps high voltage in one area

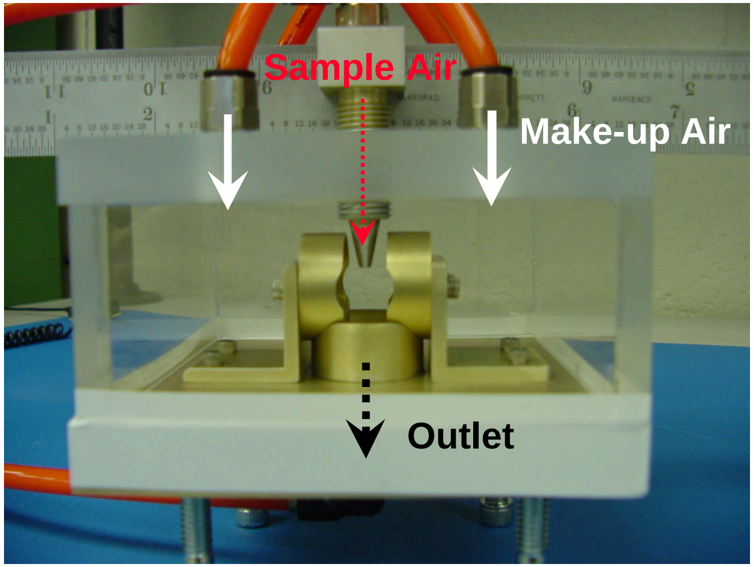
Electronics Compartment Contains Blower & Ducting
- Fan Cooled

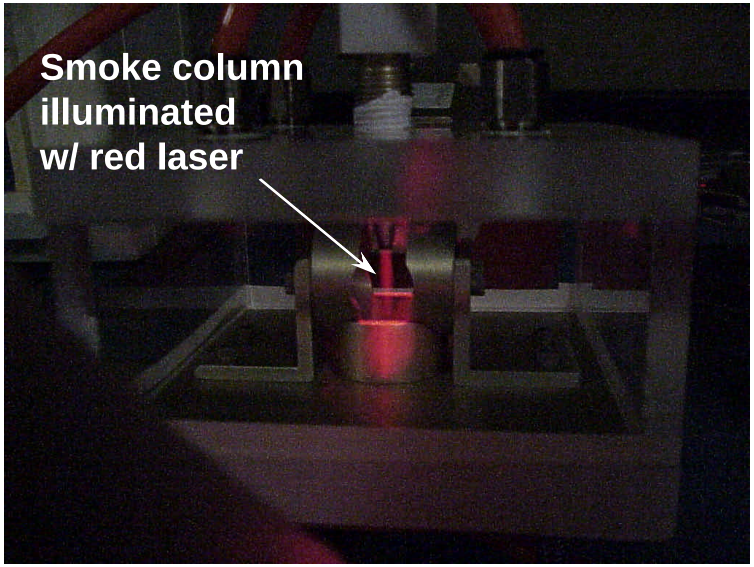
Cross Section Through Sample Chamber



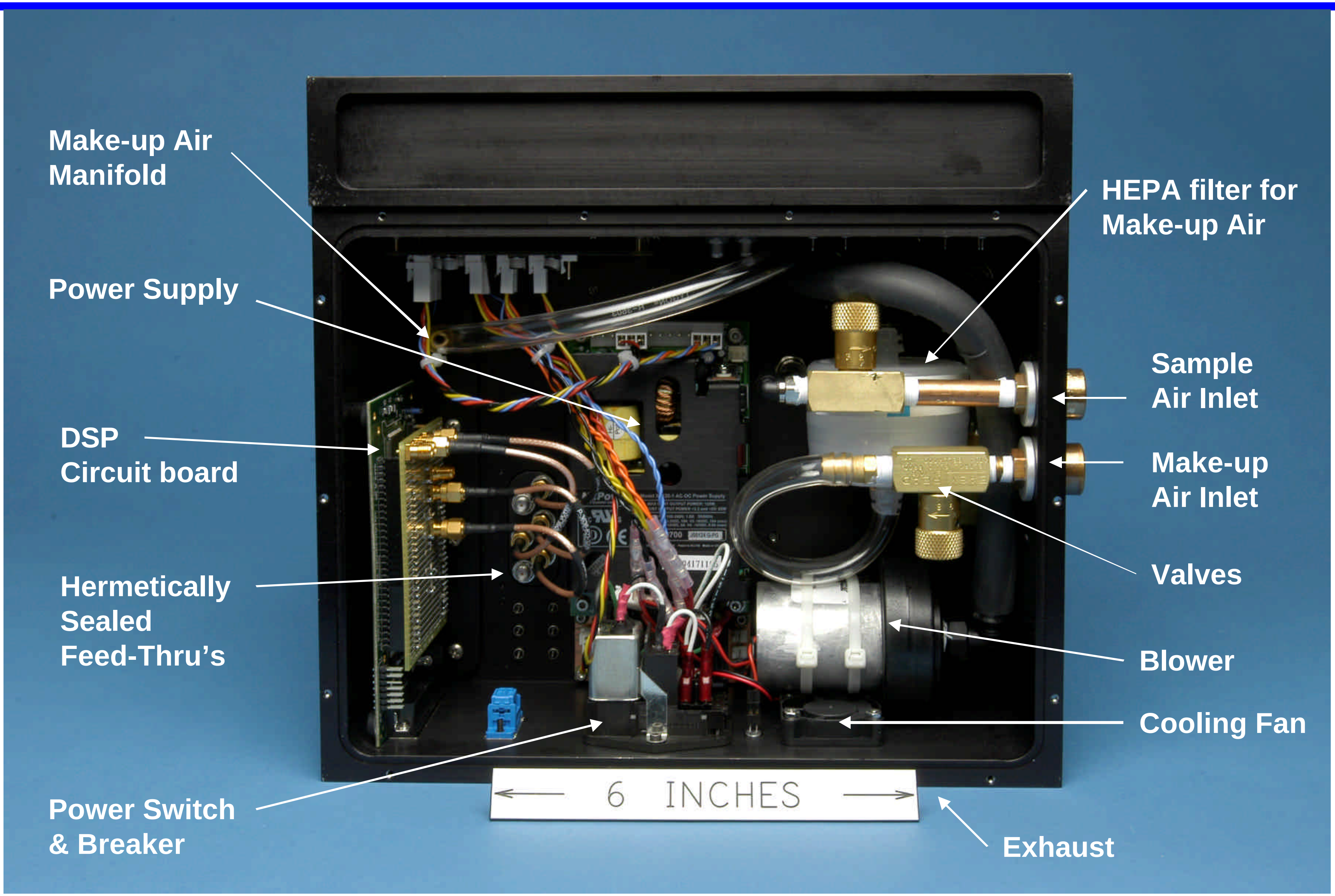
Test Chamber to Verify Airflow

- **Require sample air jet to be laminar**
  - Provides a straight particle trajectory
  - Prevents dirty optics which would cause scattered light
  - Allows accurate measurement of airflow velocity
- **Test model was used to help analyze flow**
  - Design uses a inlet nozzle with make-up air supplied from outside the collector optics
  - Smoke was used to allow visualization of airflow
- **Make-up air flow rate is 10X the sample air flow rate**

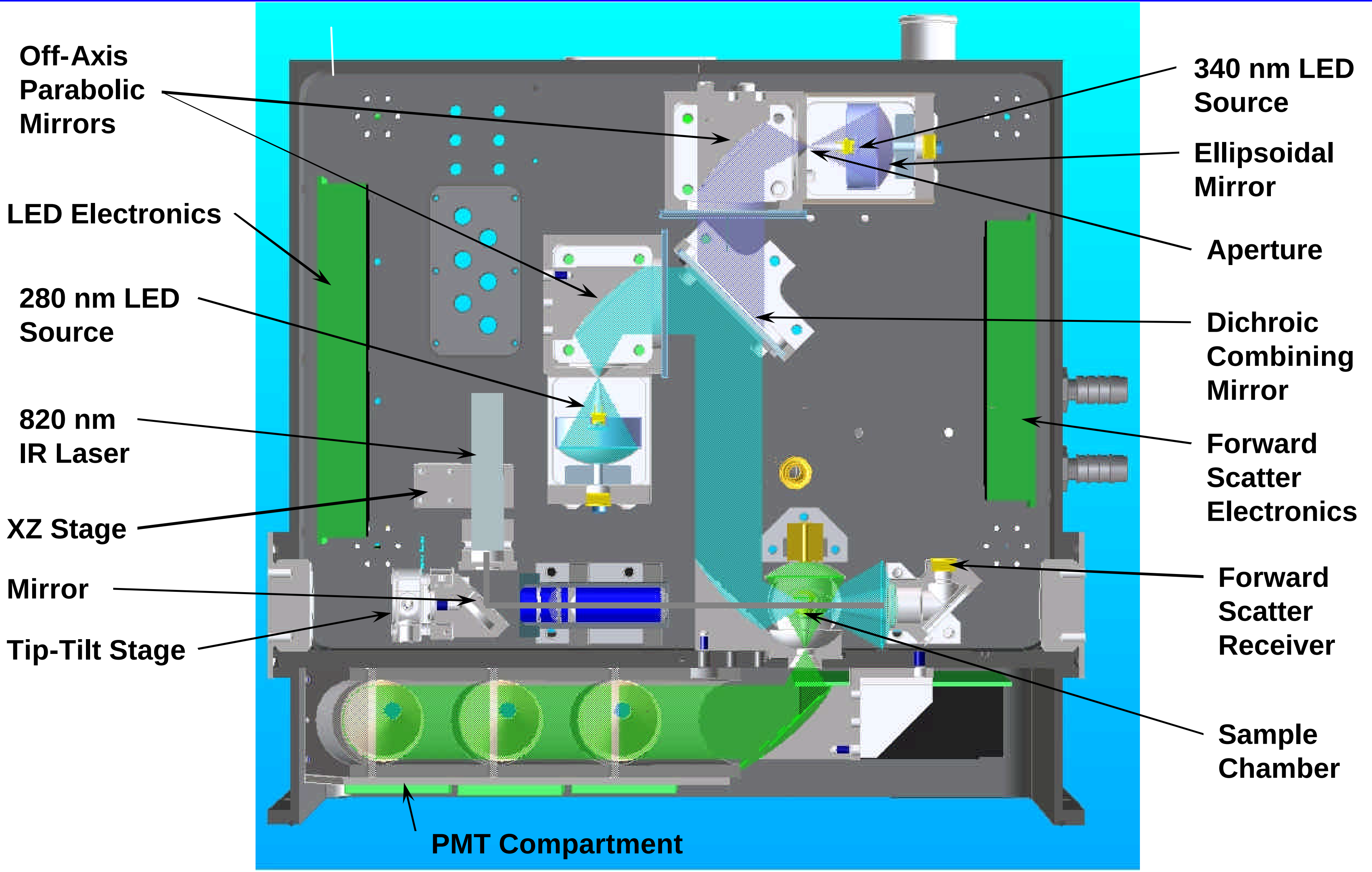




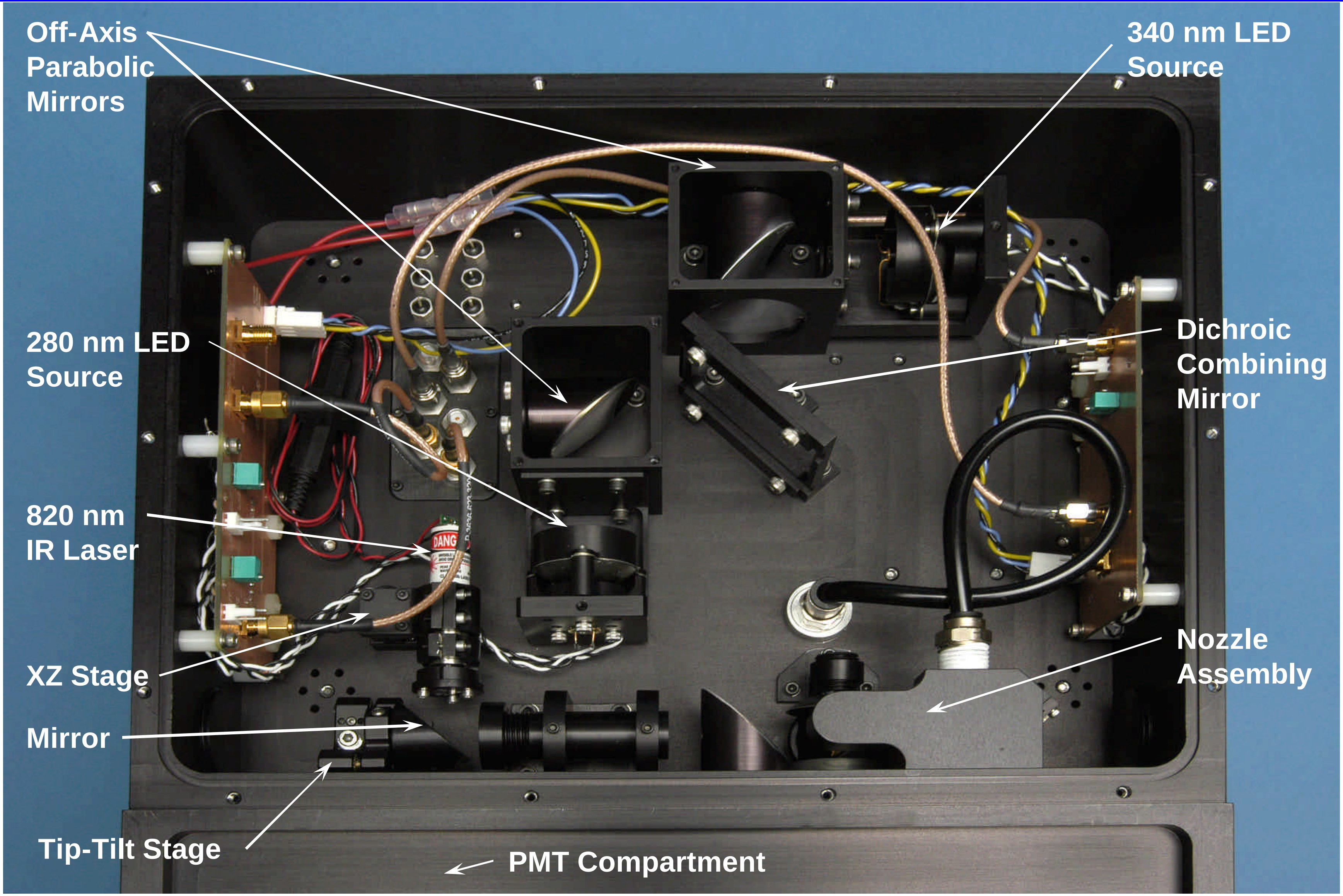
Electronics Compartment



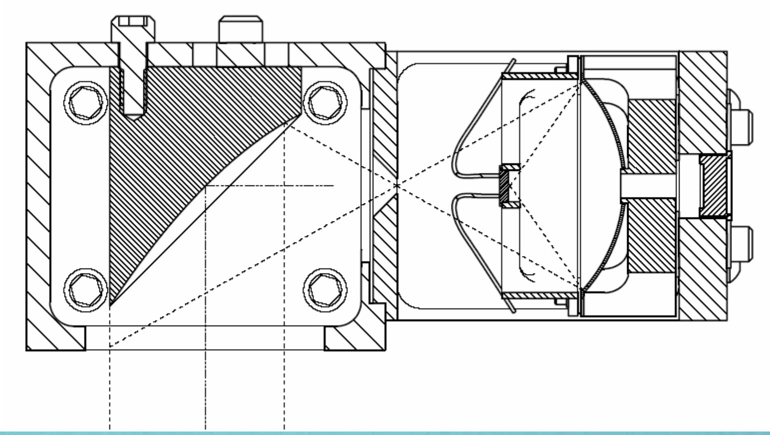
Section showing Mechanical Layout of Optics

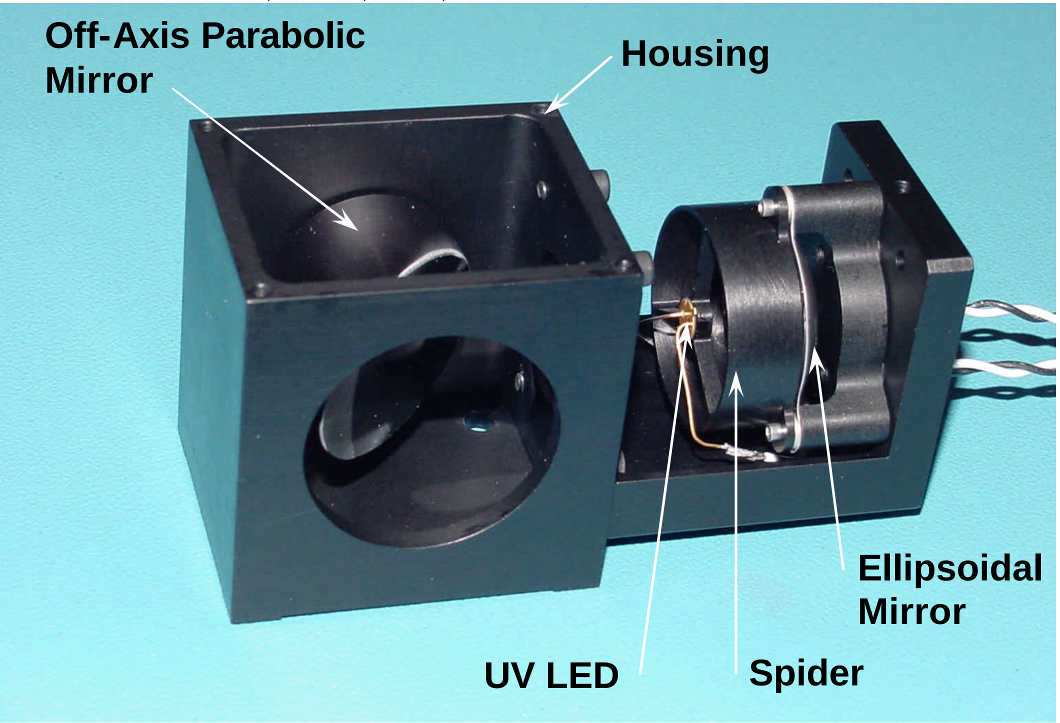


Optics Compartment



Detail of UV LED Source

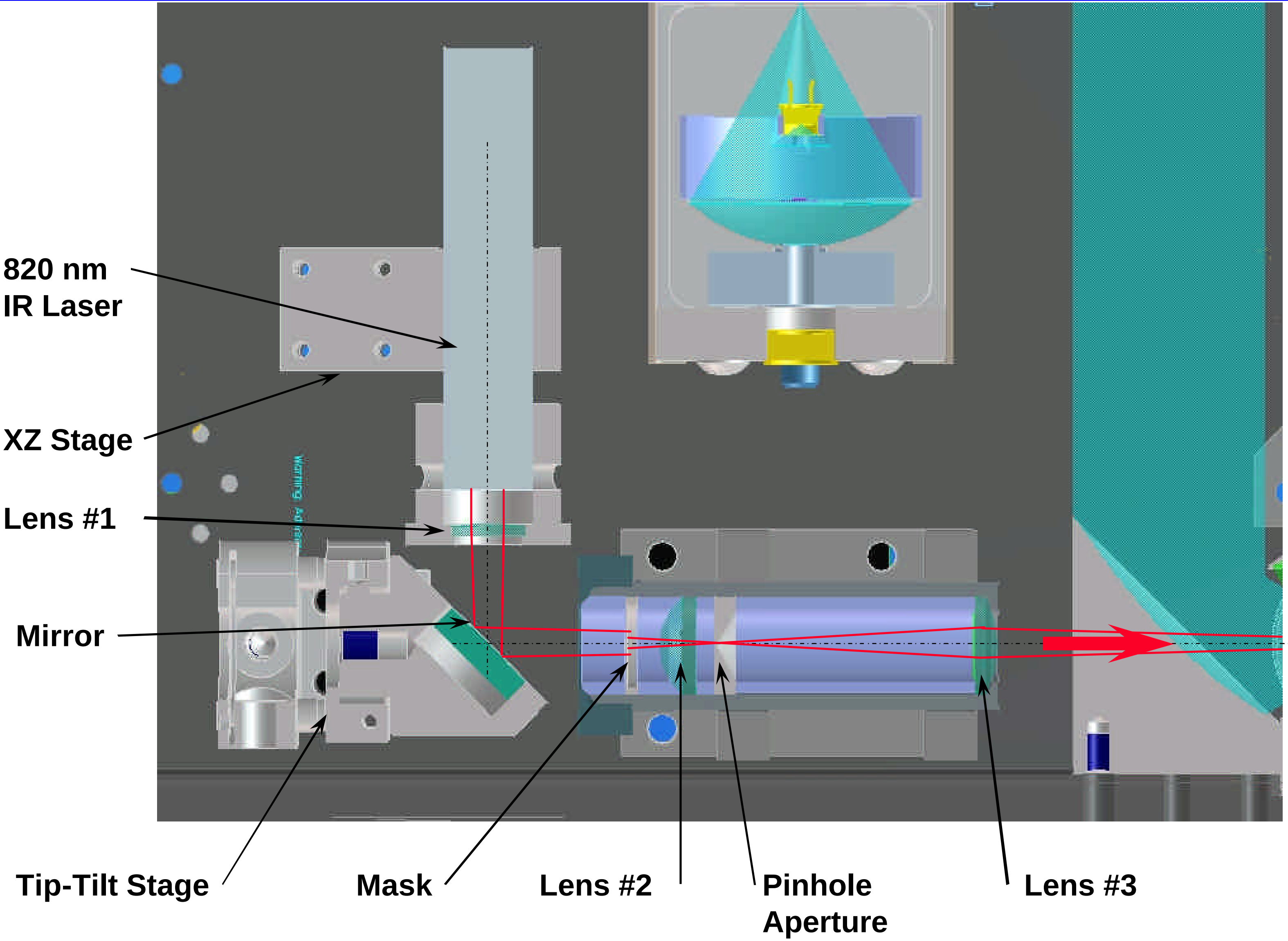




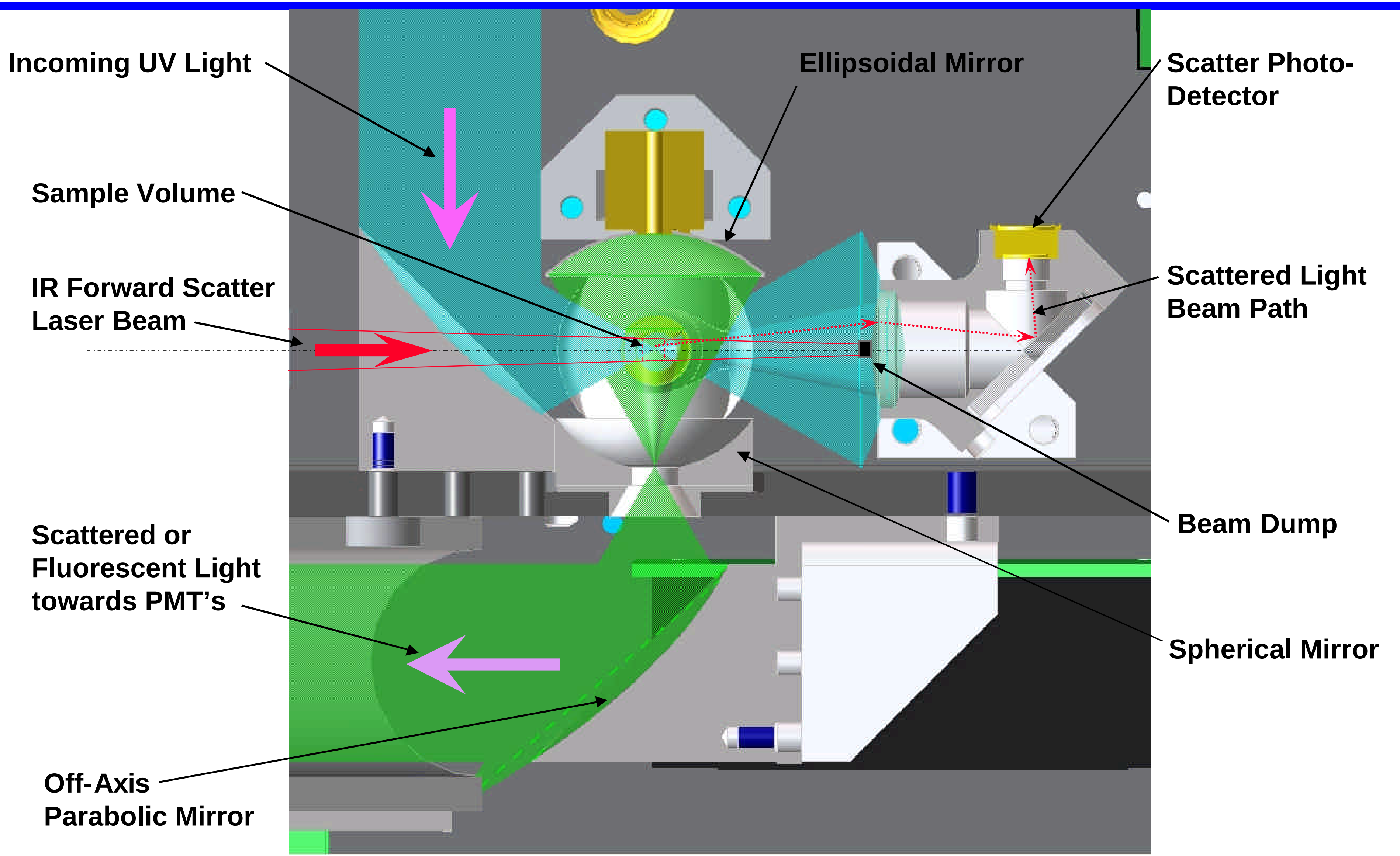
LED Source design

- Large collection angle
- Easy to align and focus
- Interchangeable mounting
- Eliminate stray light
- Allow monitoring of LED

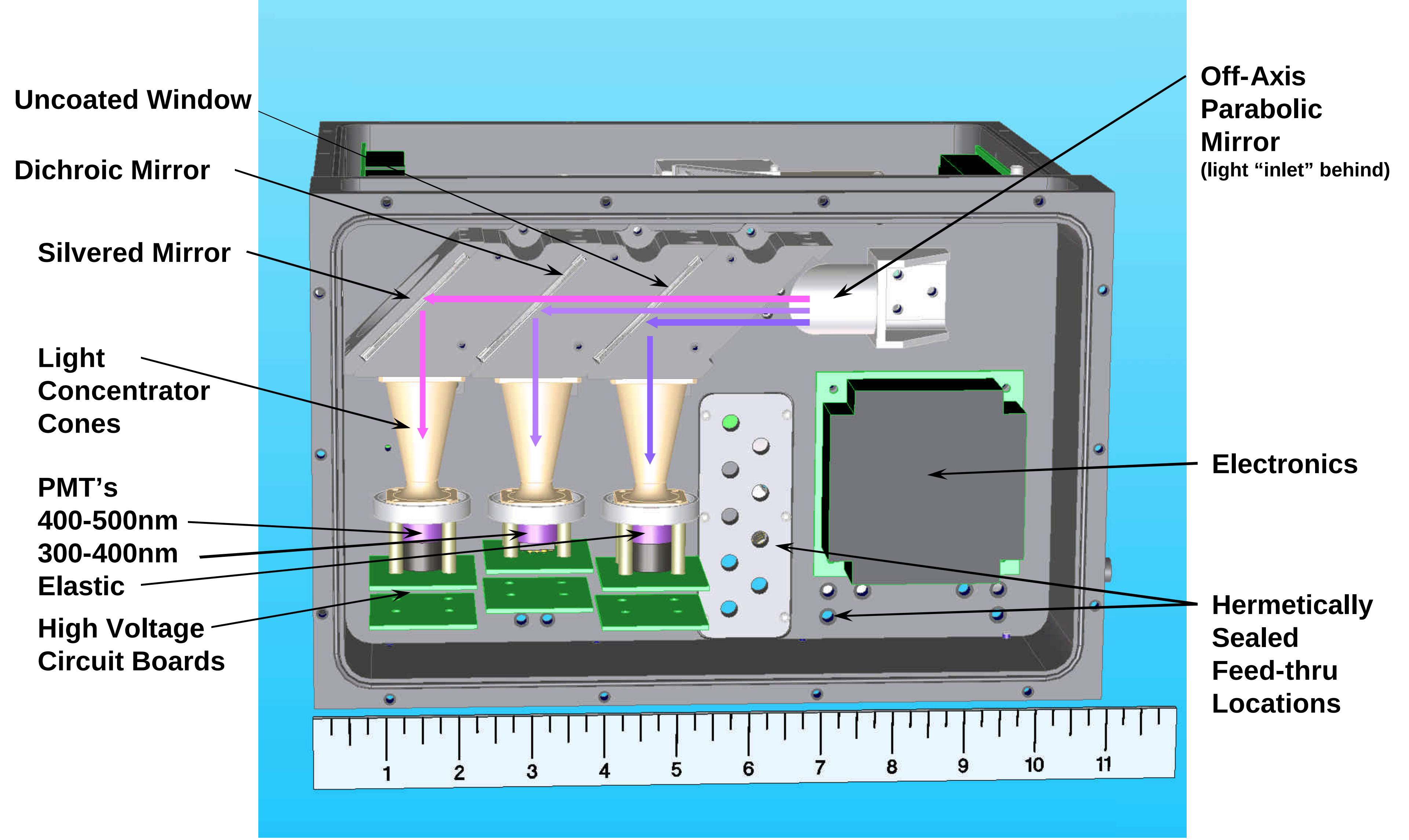
IR Forward Scatter Laser
Beam Forming



Sample Chamber Optics

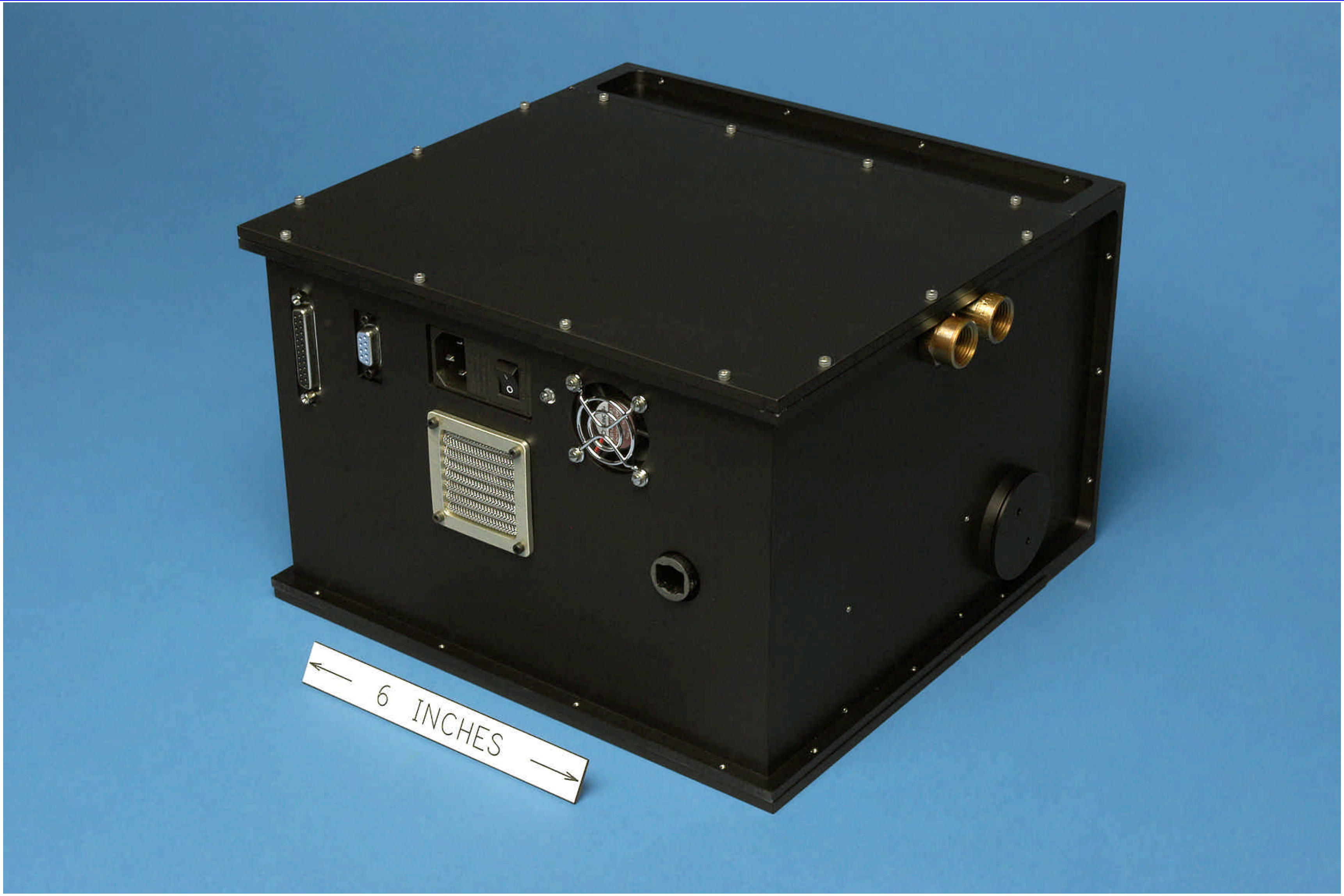


PMT Compartment Layout



PMT Compartment

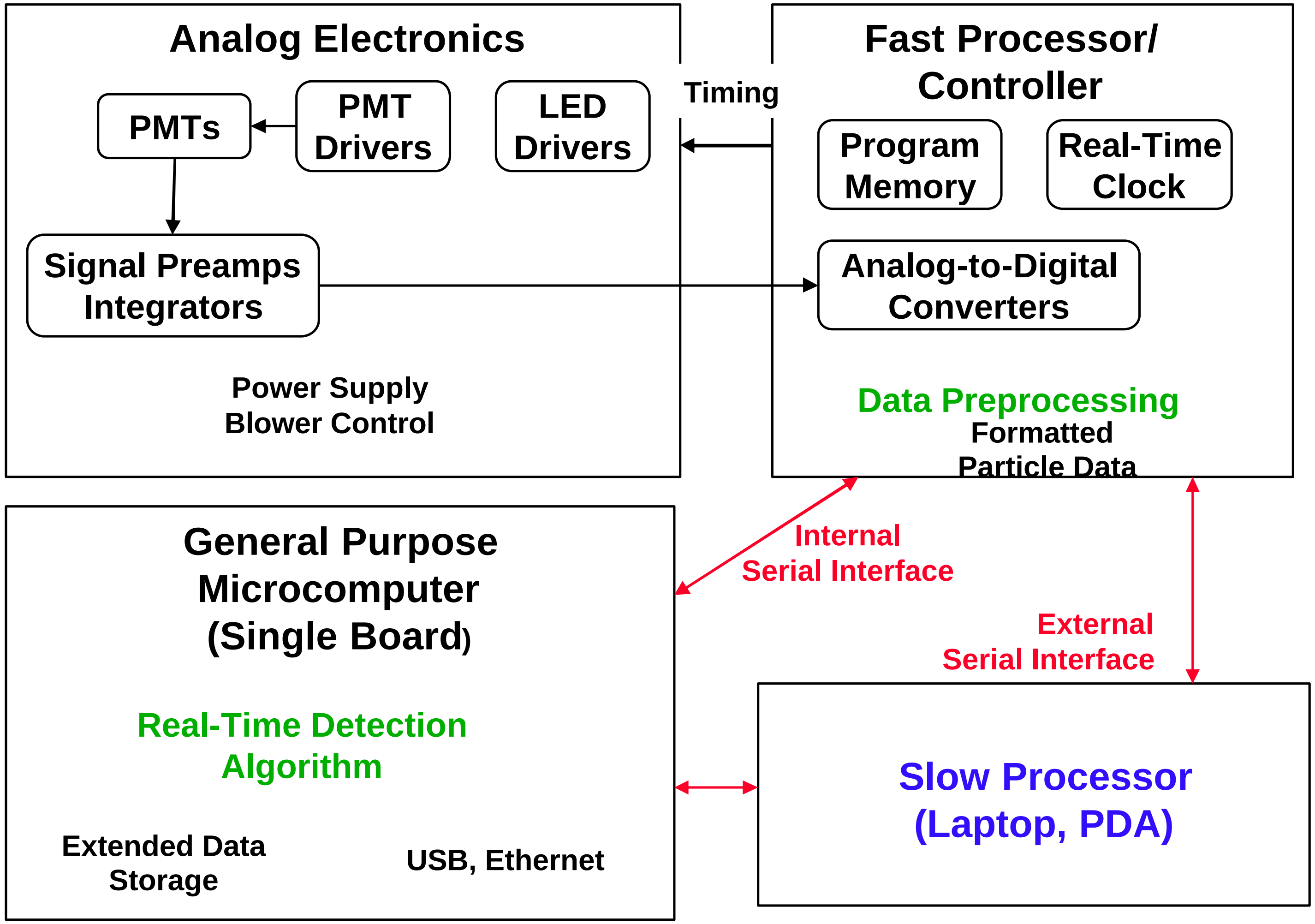
SUVOS/BAST with Covers Installed



Biological Agent Sensor Testbed Electrical Design

Engineering Development Unit Design: Electronics

Electronics Block Diagram



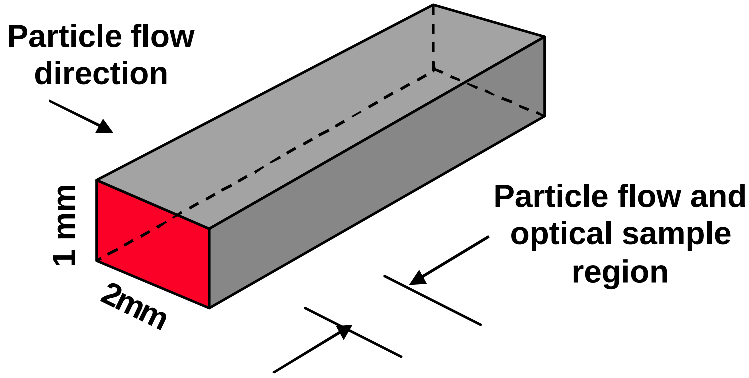
Outline

- System operation
  - Trigger and UV beams
  - Signal capture
- Hardware design
  - Design philosophy
  - Block diagrams
  - Board layouts
- Summary

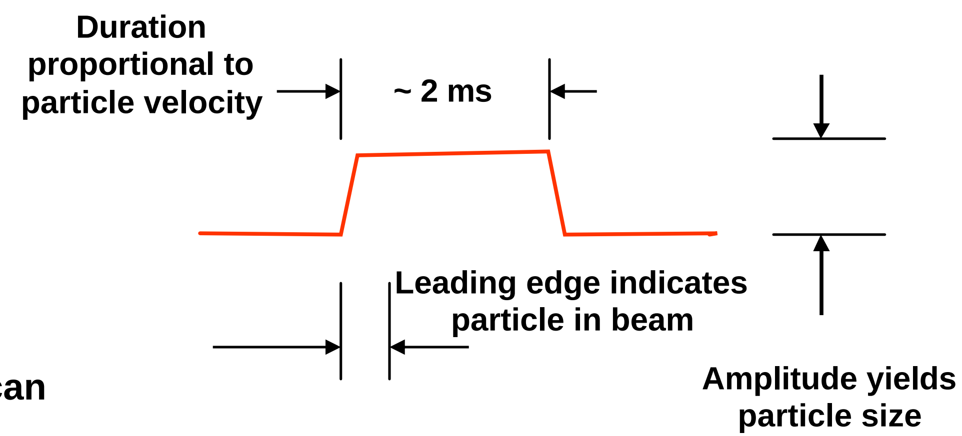
Trigger Beam

- **Excitation**
  - 820 nm CW laser diode, 8 mW
  - Conditioning optics creates flat top beam profile
- **Detection**
  - Forward elastic scatter
    - 2 to 10 degrees
  - Silicon photodiode with integral amplifier
- **Sampling rate**
  - 60 kHz
- **Functions**
  - Particle detect
    - Trigger UV sources
  - Particle size estimate
    - Primary particle descriptor
  - Velocity
    - Yields correction factor for time in beam
    - Average of many particles can be used to control blower

Beam Geometry



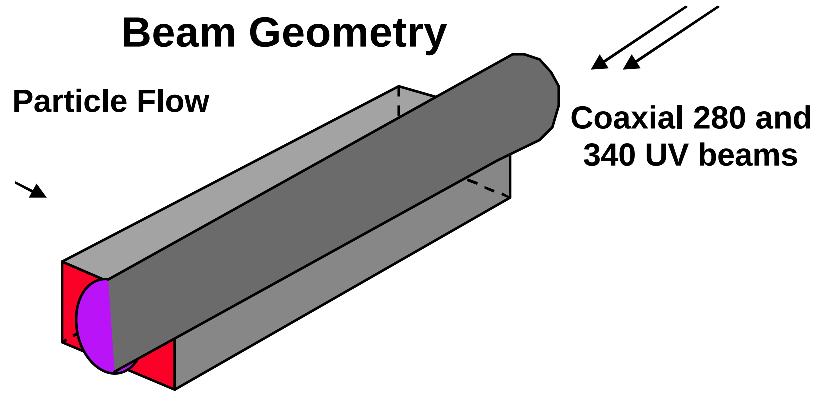
Output Signal



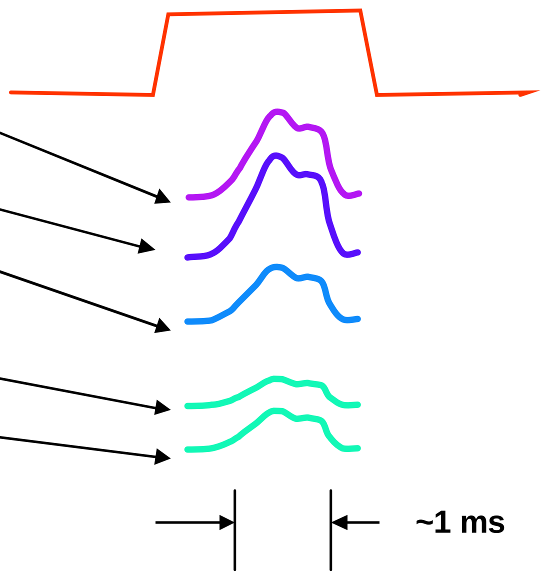
UV Beams

- **Excitation**
  - **280 nm LED**
    - **0.15 mW CW, 0.45 mW pulsed**
  - **340 nm LED**
    - **0.8 mW CW, 8 mW pulsed**
- **Detection**
  - **PMT 1, 280 nm**
    - **Elastic scatter @ 280nm**
  - **PMT 2, 300 - 400 nm**
    - **Elastic scatter @ 340**
    - **Fluorescence due to 280 excitation**
  - **PMT 3, 400- 500 nm**
    - **Fluorescence due to 280 excitation**
    - **Fluorescence due to 340 excitation**

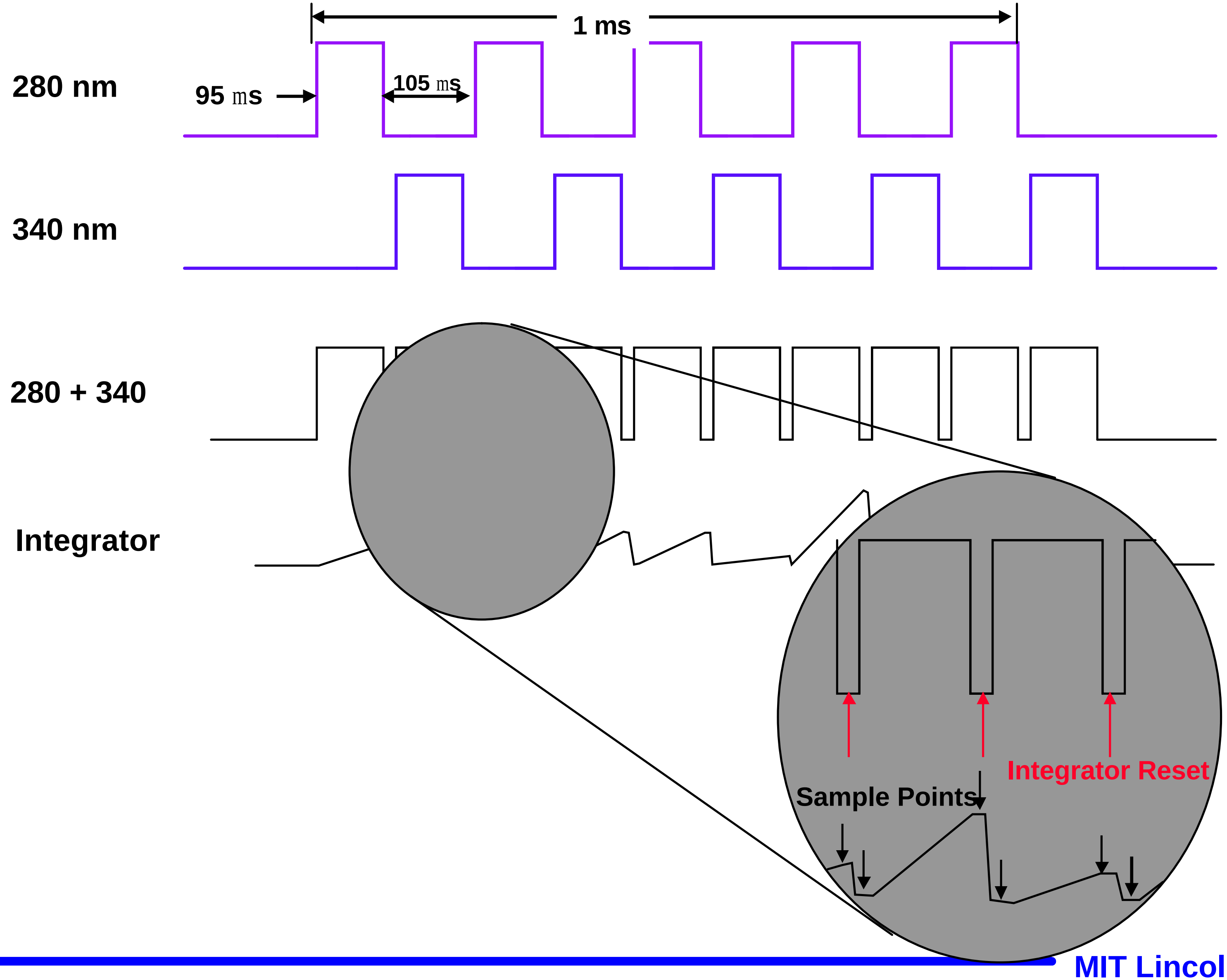
Beam Geometry

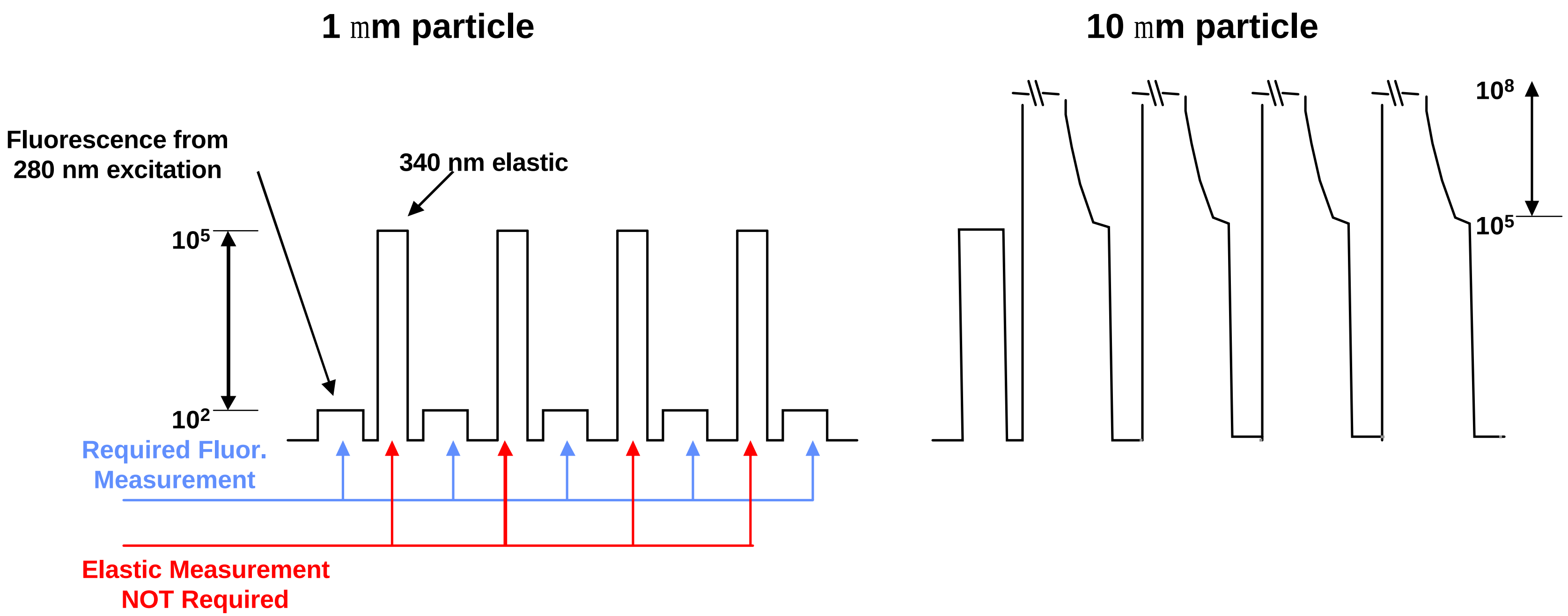


Output Signal



Time-Multiplexed UV Signals





- Elastic signal is >1000x as bright as fluorescent
- PMT saturates on large particles, losing capability to detect fluorescent signature
- Solution – Squelch the gain on PMT when elastic signal is present

Signal Estimation

- **All particle features (size, fluorescence, color) are measured relative to standard calibration particles**
  - **Typical cal target: 2 μm polystyrene spheres**
  - **Calibration particle features are assumed consistent from particle to particle**
  - **Removes need for absolute measurements**
- **Calibration Phase**
  - **Perform instrumented aerosol chamber tests with cal targets**
  - **Measure conversion factor (C)**

    $PPL_{aerosol}$ = C * (Particle counts/sec), where C is a function of airflow through instrument as estimated by particle velocity E[V]
  - **Determine measurement noise using cal target statistics**
- **Measurement phase**
  - **Correct raw scatter measurements by**

    Particle velocity (time in beam)

    Intensity of light sources (as measured by LED monitoring circuit)

Outline

- System operation
  - Trigger and UV beams
  - Signal capture
- Hardware design
  - Design philosophy
  - Block diagrams
  - Board layouts
- Summary

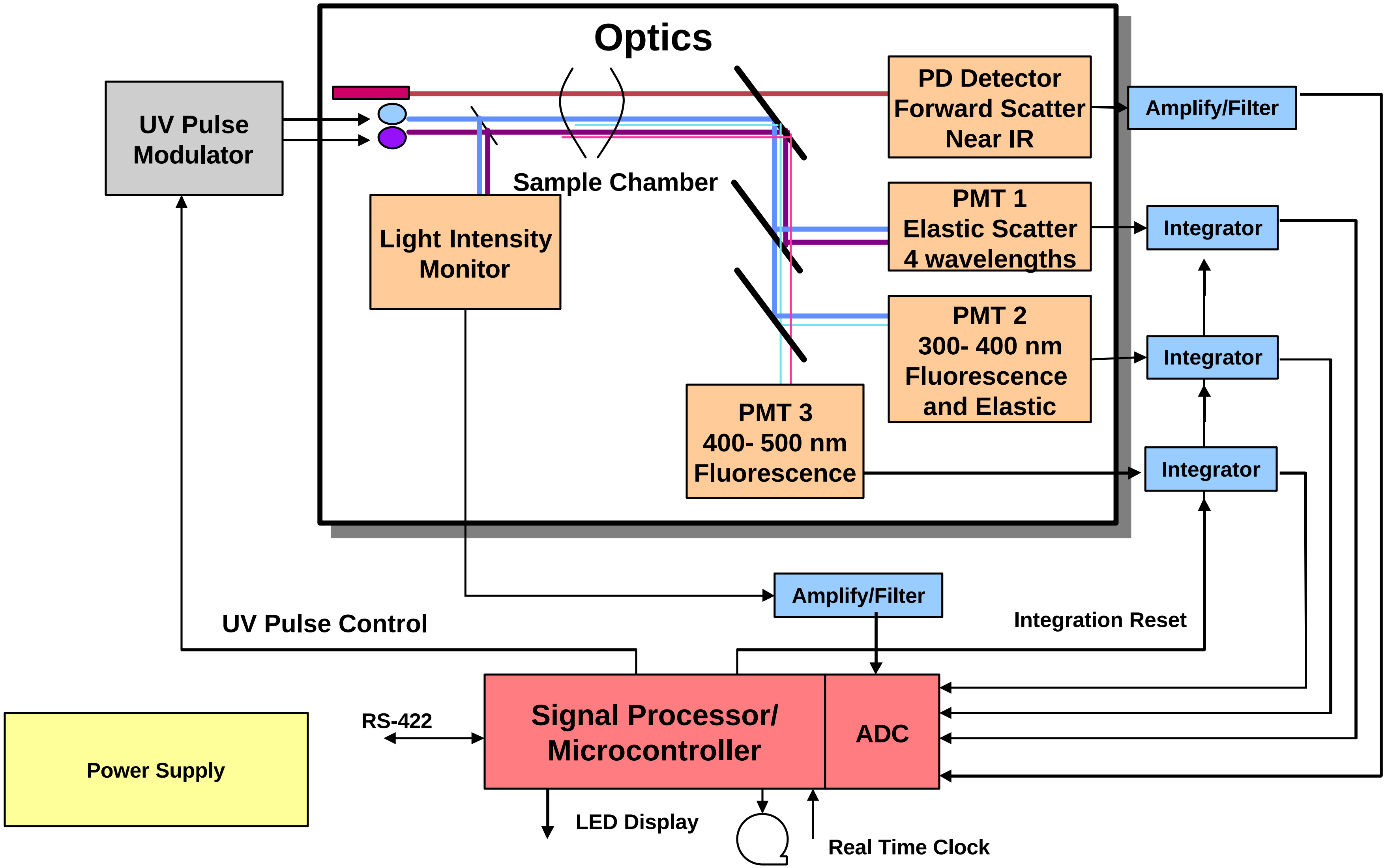
Design Philosophy

- **Use powerful COTS Digital Signal Processor/Microcontroller**
  - Built in timing and processing for time critical decisions
  - Analog-to-digital converters built into circuit
  - Ability to observe any part of code or signals through development workstation

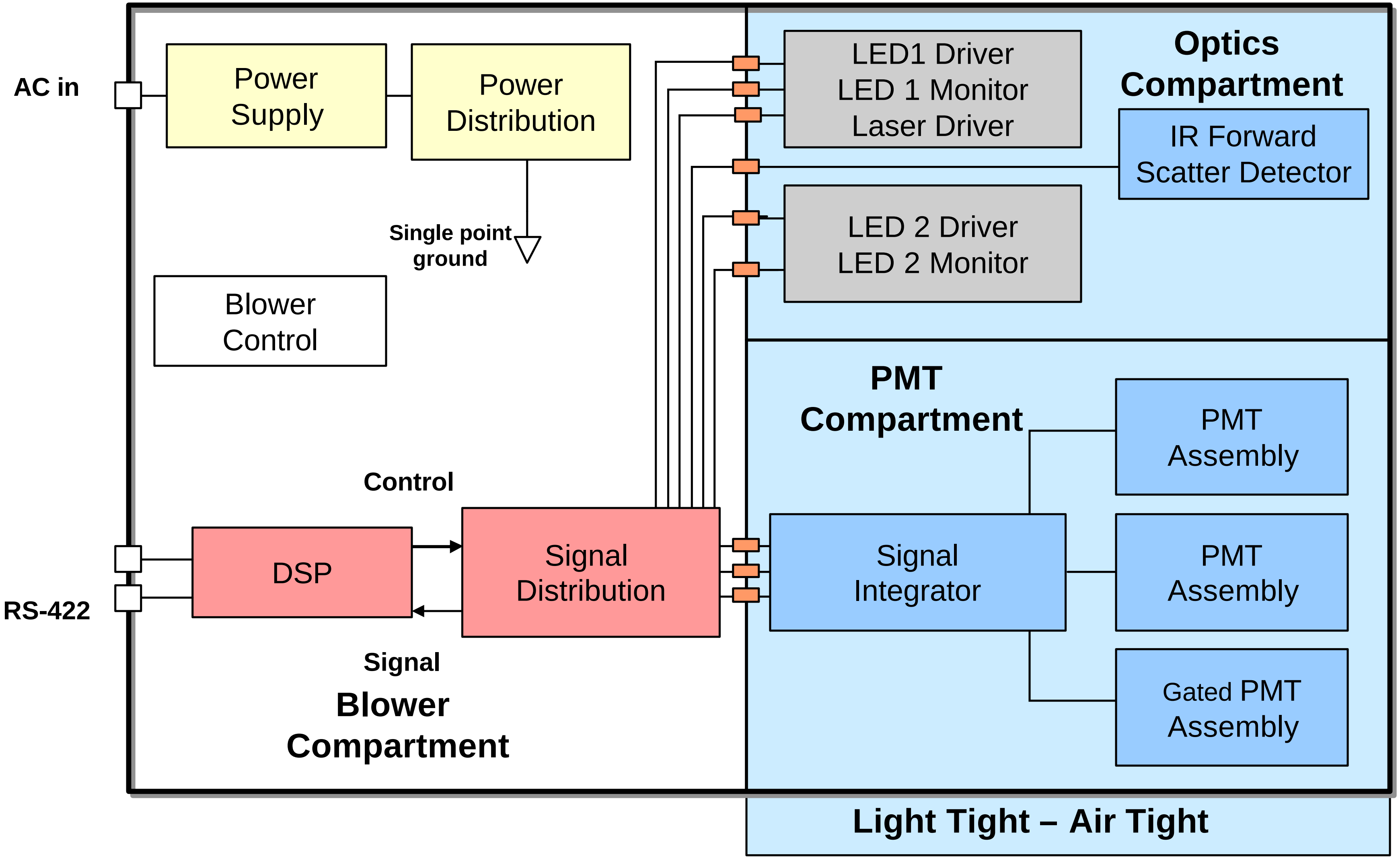
- **“Hand build” simple, distributed analog boards**
  - Single layer boards, routed on prototype machine
  - Small investment in each board - change as needed

- **Data products are vector of characteristics for each particle**
  - Formatted and serially transmit, readable by any general purpose computer
  - Algorithm development and deep memory resides on general purpose computer
  - On completion of algorithm development the algorithm is ported to the DSP, or if necessary a separate embedded microcontroller

Electronics Block Diagram



Electronics Board Configuration

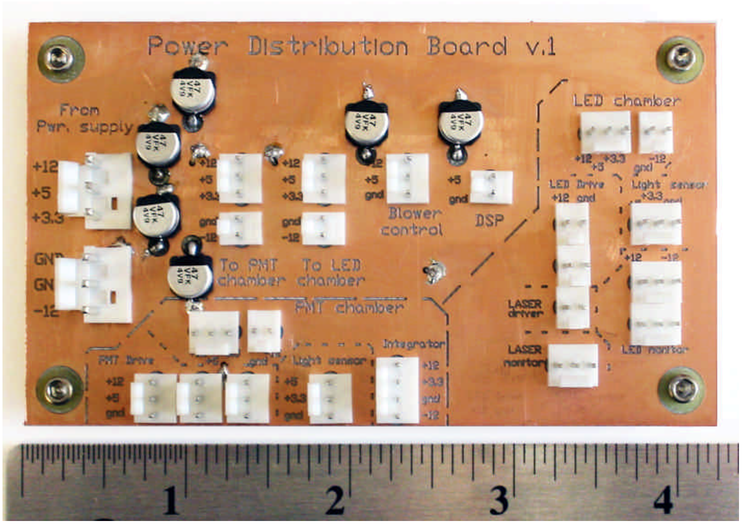


Power System

COTS AC to DC Power Supply

- **Type**
  - **Switching supply**
  - **125W Capacity**
    - **Power consumption = 53 W**
- **Input**
  - **125VAC, ~1A**
- **Output**
  - **+12 VDC, 5A**
  - **+5 VDC, 15A**
  - **+3.3 VDC, 10A**
  - **-12VDC, 0.5A**
- **Size**
  - **3” x 5” x 1.25”**

Power Distribution Board



- **Output**
  - **Separate power for each of three compartments**
- **Filtering**
  - **Medium and high frequency noise filters**
  - **Ripple 20mv p-p, with fan running**
  - **Additional filtering on satellite boards**
- **Size**
  - **2.5” x 4.25” x .75”**

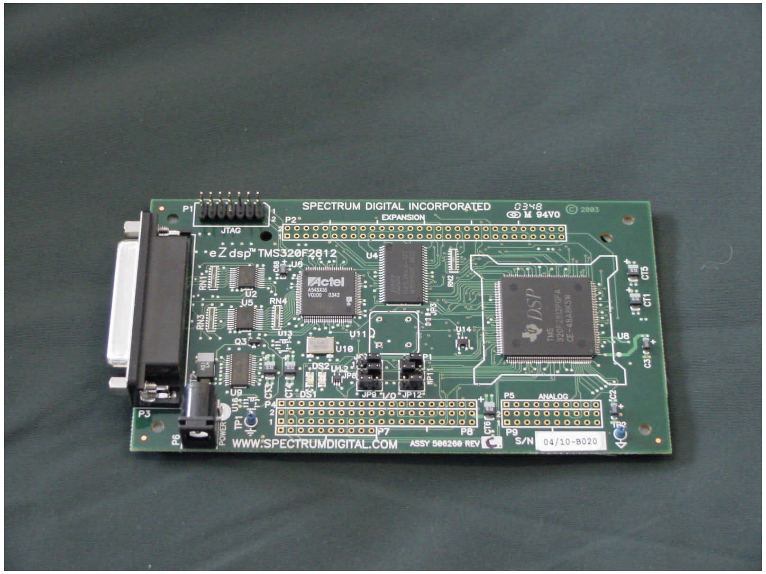
DSP/Microcontroller

Texas Instruments TMS320F2812

- Unifies microcontroller peripherals with DSP processing power
  - 128K of flash and 18K of RAM
- 32-bit Harvard Architecture Processor with MAC
  - Runs at 150 MHz for 6.67ns instruction time
- On-board peripherals
  - Analog-to-Digital Converter
    - 2 x 8 Channel 12.5 MSPS
    - 12-bit resolution
  - Pulse width modulation outputs
  - 56 general purpose digital ports
    - 20 MHz modulation rate max
  - Serial ports
  - Controller Area Network (CAN) Interface
  - Watchdog timer
- Real-time operating system
- Unit cost $25 (bare chip)

Digital Signal Processing Evaluation Board

- **Spectrum Digital DSP evaluation board**
  - Interface headers
  - On board memory
  - JTAG ports
  - Cost ~$450



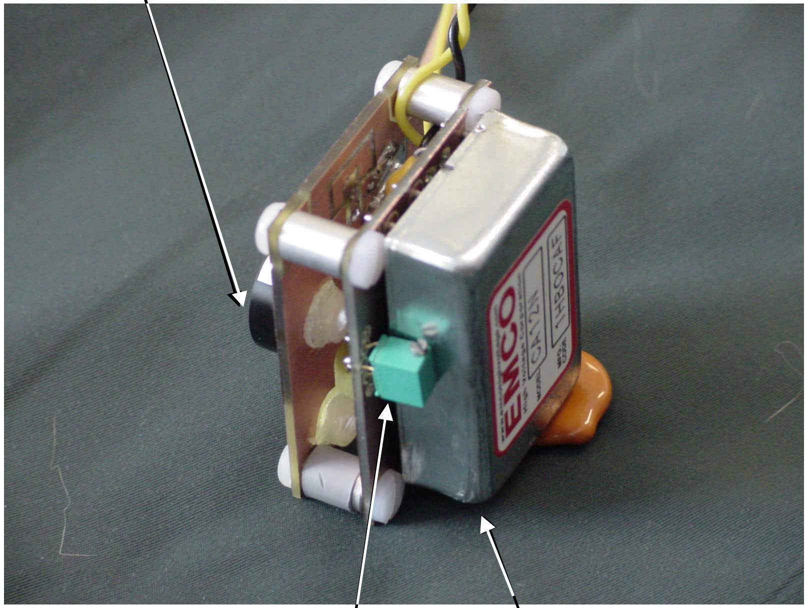
- **Custom built distribution board**
  - Connects control and analog signals from DSP board to distributed analog boards

PMT Module

- **Photomultiplier Tube, Hamamatsu R7400-03**
  - Gain = 10^6
  - Dark current <1nA
  - Sensitivity = 62mA/W
  - Size = 1.75” x 0.75” x 0.5”
  - Operating voltage = -800 VDC

- **Power Supply, EMCO CA12N**
  - 0 to -1250 VDC, 800mA max current
  - 12VDC input, <220 mA
  - Ripple <0.0005%
  - Size = 1.75” x 0.75” x 0.5”

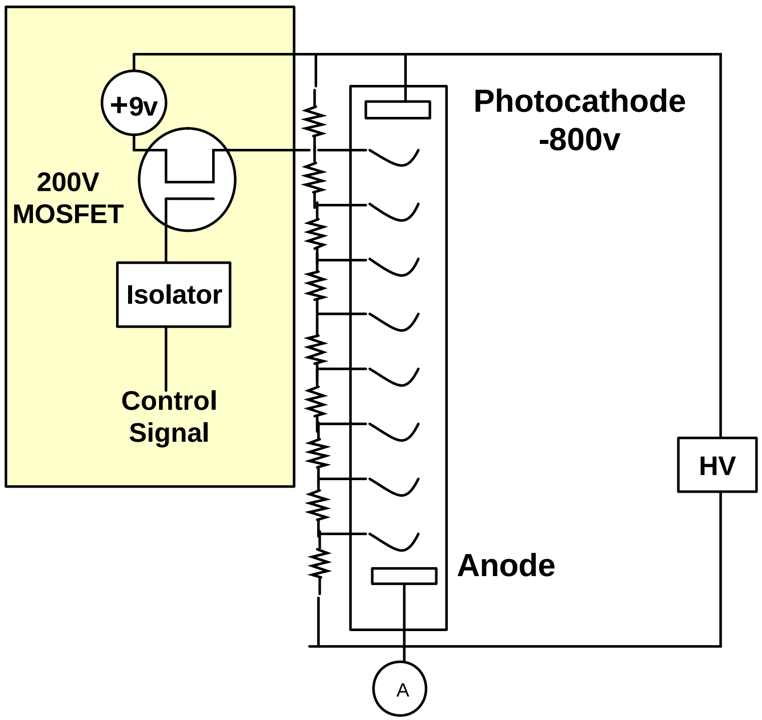
- **Mounting**
  - Custom pair of boards designed for small form factor
  - Accurate alignment with light cone through mounting arrangement



Gated PMT Module

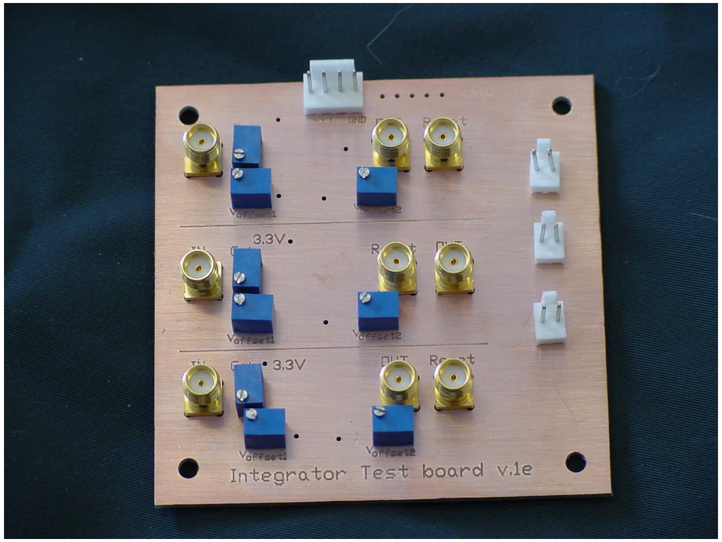
- **Gain reduction**
  - **100X**
- **Switching speed**
  - **< 4μs**

Gating Circuit



PMT Signal Integrator

- **3 channel signal integration - one for each PMT**
- **Two gain settings for scatter and fluorescence measurements**
- **>3 log dynamic range in each channel**
- **Sample at beginning and end of integration cycle to reduce inaccuracies in reset**
  - **Measure when no signal present to determine offset current**



LED Driver and Monitor

- **LED Driver**
  - **Precision current source controlled by linear regulator and potentiometer**
  - **Switching rates of 5kHz up to 200mA**

- **LED Monitor**
  - **Transimpedence amplifier with adjustable gain**
  - **Particles < 1μm detectable**

Data Flow at Signal Processor Output

- Maximum particle rate = 100 particles / second
  - Based on 1 ms pulse width
  - 10% duty cycle for UV LED
  - 10,000 ppl concentration
- Particle characterization
  - 10 descriptors
  - Timestamp, 4 bytes
    - Matlab format
- Data format
  - Fixed length record 20 bytes/particle
- Signal rate
  - Maximum ~2 KB/sec
    - 175 MB/day
  - Typical (1000 ppl background) ~200 B/sec
    - 17 MB/day

Summary

- BAST electronics have been developed for support of a triggered, multi-band particle measurement instrument
- The electronics combines COTS and custom components
- No major issues have been uncovered in the development of the electronics

Biological Agent Sensor Testbed Algorithm Development

Algorithm Development Goals

- **Develop real-time detection algorithm**
  - **Detection of threat-like <u>change</u> in ambient aerosol**
- **Operate in typical background conditions**
  - **Good sensitivity**
  - **High probability of detection**
  - **Fast response time**
  - **Low false positive rate**
- **Leverage previous experience with triggered point-detection bio-sensors and detection algorithms**

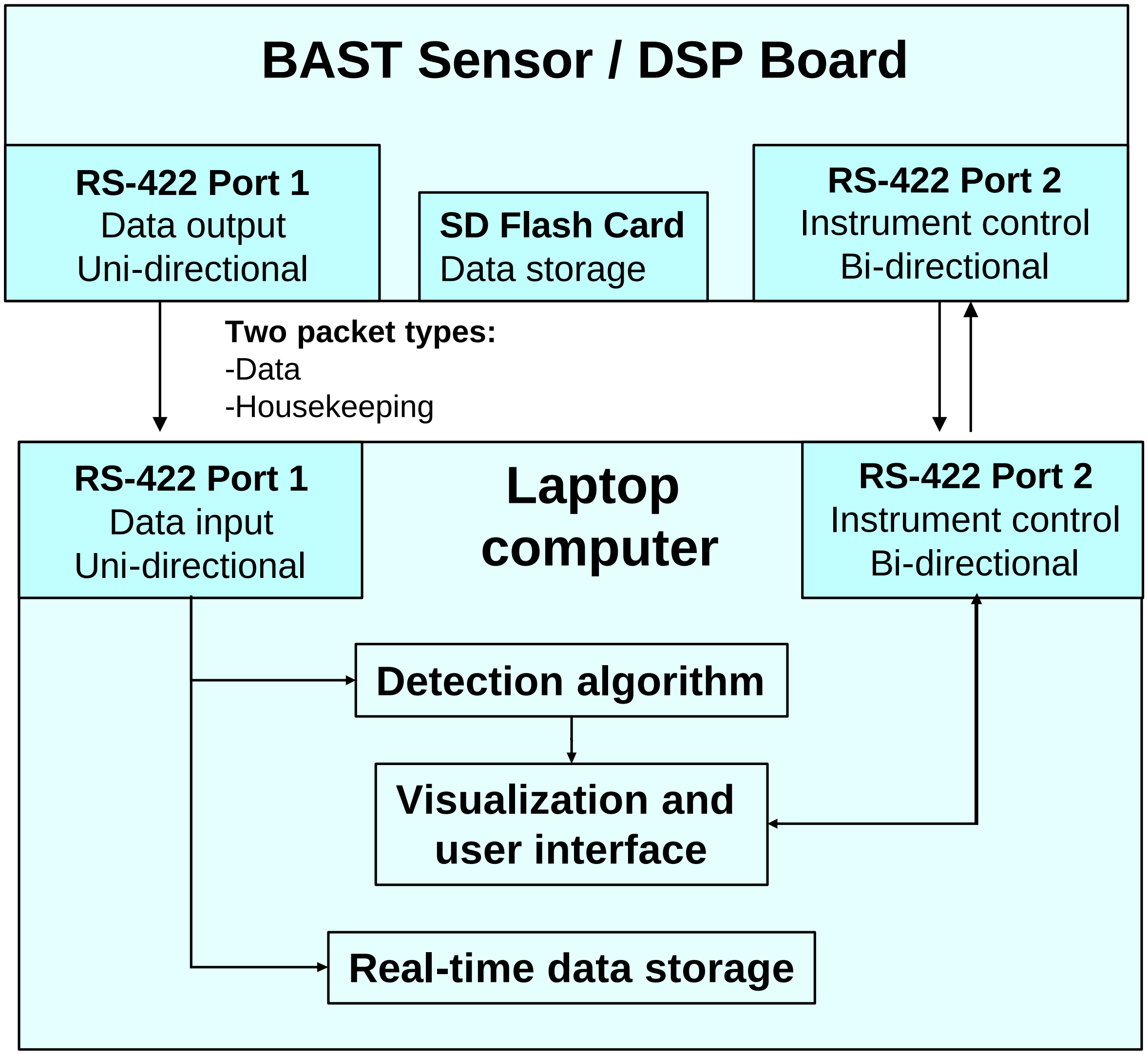
Data Flow to Algorithm

- **Particle Measurements**
  - 280-nm elastic scattering
  - 300 - 400 nm fluor. (280-nm ex.)
  - 400 - 500 nm fluor. (280-nm ex.)
  - 400 - 500 nm fluor. (340-nm ex.)
  - IR scattering (820 nm)
  - Particle transit time
  - LED power
  - Timestamp

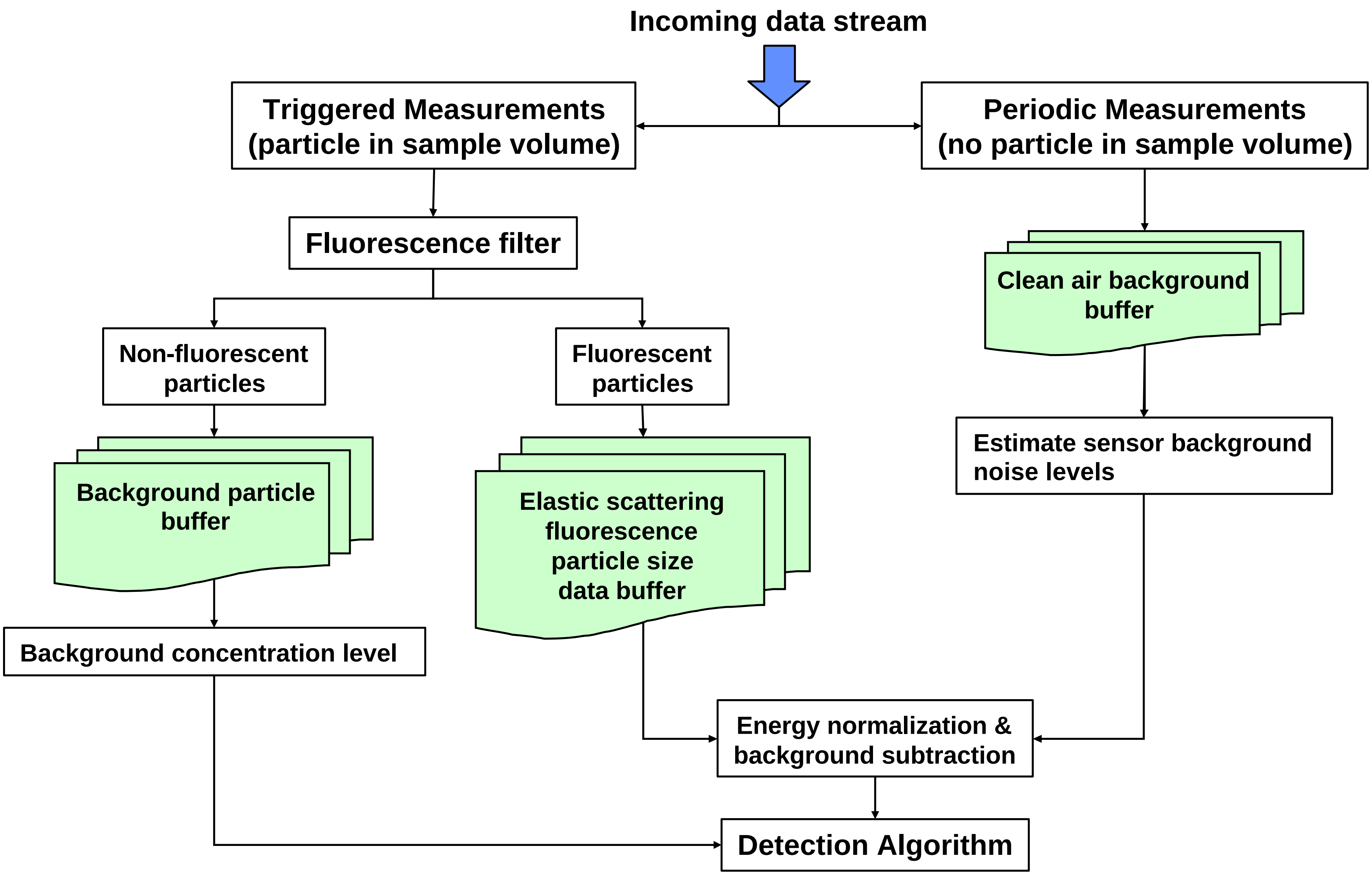
- Particle triggered
  - Raw particle signal
- Periodic (1 Hz)
  - Sensor noise
- Particle signal = raw particle signal – sensor noise

- **Housekeeping Measurements**
  - Airflow
  - LED operation time
  - System voltages
  - Etc…

Data Collection and Instrument Control



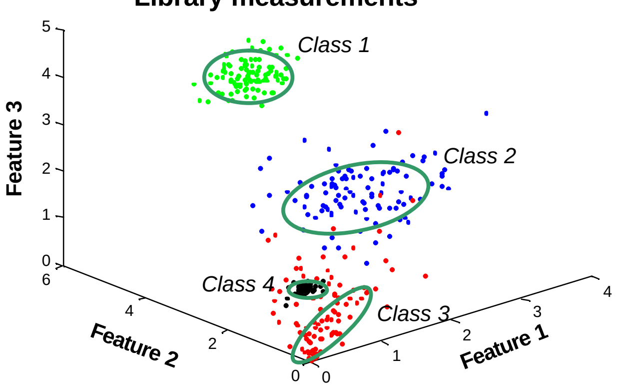
Algorithm Pre-processing



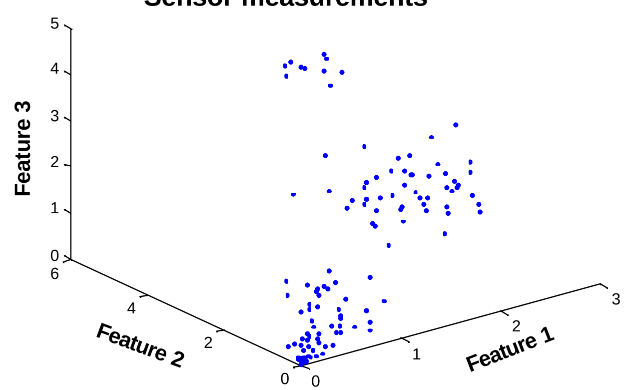
Algorithm Concept

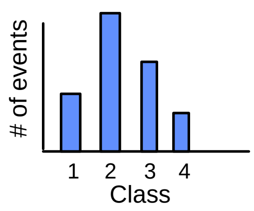
- **Separate particles into broad classes based on position in feature space**
  - **Directly measured features (e.g. elastic scattering, fluorescence, etc.)**
  - **Derived features (e.g. fluorescence/scattering ratio, spectral histogram, higher order statistics, etc.)**
  - **Regions defined by library of laboratory and field measurements**
- **Track running histogram of occurrences for each class**
- **Positive detection if:**
  - **Number of occurrence in any class exceeds predefined threshold count (100 particles)**
- **Maximum response time one minute (minimum time about 10 seconds)**

Library measurements



Sensor measurements





High or Fluctuating Clutter Conditions

- **Ambient background conditions can vary dramatically with sensor location and operating environment**
- **Very high particle backgrounds can effectively “blind” the sensor to threat particles**
- **Track background concentration and correct measured threat particle concentration**
- **Several possible responses to this condition**
  - **Raise particle size threshold**
  - **Raise concentration threshold**
  - **Alert user to potential sensitivity reduction**

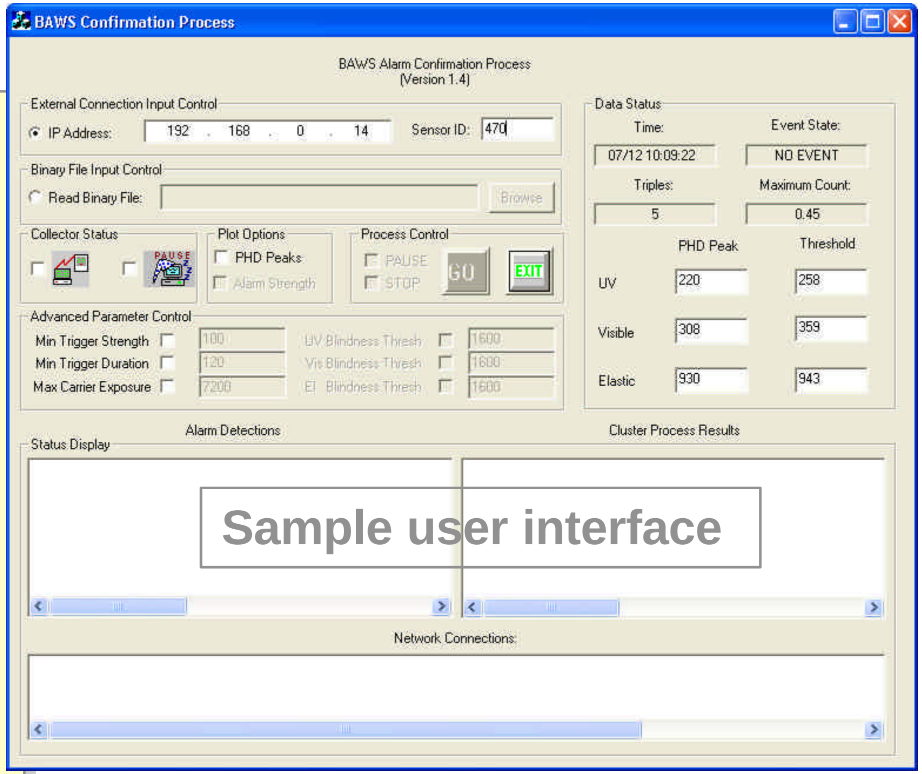
User Interface Development

Visualization and Analysis Tools

- **Development Interface**
  - **Access to all relevant signals**
    - **Buffered analog test points**
    - **Digital outputs**
  - **Real Time Displays**

- **Field Testing Interface**
  - **Event data (standard detection algorithm output)**
  - **Real-time particle data**
    - **Summary statistics and time series**
  - **Diagnostics**

- **End User Interface**
  - **Trigger status**
  - **Sensor health status**
  - **Optional algorithm outputs over ethernet and/or serial port**



- **Verify incoming signals (“quick-look” data tools)**

- **Flexible visualization to support algorithm development**
  - **immediate feedback**
  - **modular**

Summary

- Developed an architecture for a real-time algorithm to detect potential threat aerosols
- Leverage prior experiences and lessons learned from previous bio-detection sensor systems and field measurements
- UV induced fluorescence has been shown be a good indicator of the presence of biological particles
- With five independent measurements we hope to increase discrimination between threat and non-threat particles